ARCHITECTURAL ENERGETICS IN ARCHAEOLOGY

ANALYTICAL EXPANSIONS AND GLOBAL EXPLORATIONS

Edited by

Leah McCurdy and Elliot M. Abrams

ROUTLEDGE

Architectural Energetics in Archaeology

Archaeologists and the public at large have long been fascinated by monumental architecture built by past societies. Whether considering the earthworks in the Ohio Valley or the grandest pyramids in Egypt and Mexico, people have been curious as to how pre-modern societies with limited technology were capable of constructing monuments of such outstanding scale and quality. Architectural energetics is a methodology within archaeology that generates estimates of the amount of labor and time allocated to construct these past monuments. This methodology allows for detailed analyses of architecture and especially the analysis of the social power underlying such projects.

Architectural Energetics in Archaeology assembles an international array of scholars who have analyzed architecture from archaeological and historic societies using architectural energetics. It is the first such volume of its kind. In addition to applying architectural energetics to a global range of architectural works, it outlines in detail the estimates of costs that can be used in future architectural analyses.

This volume will serve archaeology and classics researchers, and lecturers teaching undergraduate and graduate courses related to social power and architecture. It also will interest architects examining past construction and engineering projects.

Leah McCurdy is a Senior Lecturer in the Department of Art & Art History at the University of Texas at Arlington (UTA) and a Research Associate with the University of Texas at San Antonio (UTSA). Leah earned her PhD from UTSA in 2016 with her dissertation focused on the application of energetics and labor analysis to the ancient Maya site of Xunantunich, Belize. Leah has been excavating at Xunantunich since 2008 to collect data relevant to her research interests in ancient construction practices, cooperative labor, the intersections of monumentality and community, as well as the meaning of the ancient built environment.

Elliot M. Abrams is Emeritus Professor of Anthropology at Ohio University. He refined and promoted the methodology of architectural energetics in *How the Maya Built Their World* (1994). In addition to his archaeological research in Mesoamerica, he has conducted excavations in the Ohio Valley for over three decades. He coedited (with AnnCorinne Freter) *The Emergence of the Moundbuilders: The Archaeology of Tribal Societies in Southeastern Ohio* (2005), which outlines the formation of sedentary tribal communities. He also studies environmental change, economic institutions, and social power through the lens of anthropological archaeology.

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Analytical Expansions and Global Explorations

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Elliot dedicates this volume to his wife, AnnCorinne, and his son, Zachary.

Leah dedicates this volume to Daniel. You are always with me. You told me so.

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Contributors

Elliot M. Abrams is Emeritus Professor of Anthropology at Ohio University. He refined and promoted the methodology of architectural energetics in *How the Maya Built Their World* (1994). In addition to his archaeological research in Mesoamerica, he has conducted excavations in the Ohio Valley for over three decades. He coedited (with AnnCorinne Freter) *The Emergence of the Moundbuilders: The Archaeology of Tribal Societies in Southeastern Ohio* (2005), which outlines the formation of sedentary tribal communities. He also studies environmental change, economic institutions, and social power through the lens of anthropological archaeology.

William M. Balco is an Assistant Professor of Anthropology at the University of North Georgia. His research explores social complexity and social entanglements in the western Mediterranean.

Jarrod Burks is the Director of Archaeological Geophysics at Ohio Valley Archaeology, Inc., a cultural resource management firm based in Columbus, Ohio. Jarrod is an expert in the application of geophysical survey techniques for archaeological contexts. In addition to his day job conducting geophysics on CRM projects and for historical societies and others, Jarrod teaches archaeological geophysics in a variety of contexts, including the annual National Park Service geophysics workshop, the Society for American Archaeology online seminar series, and in many other workshops. He spends his free time researching Hopewell settlement in central Ohio and conducting geophysical surveys at ancient earthwork sites in Ohio.

Jamie L. Davis has been employed at Ohio Valley Archaeology, Inc. since 2010 and has worked as a professional archaeologist since 2009. He earned his BA degree in anthropology and BA degree in mathematics from Ohio University in 2002 and 2006. Jamie also earned a Geographic Information Systems (GIS) master's certificate from Penn State University in 2011. Jamie is a FAA Unmanned Aerial Systems (UAS) certified remote pilot and has been performing UAS based

photogrammetry since 2015. Besides Serpent Mound, Jamie has created photogrammetry models of the Newark Octagon, the Grave Creek Mound, and Sutton Hoo, among others.

Anthony James DeLuca holds an MA in Anthropology from the University of Colorado Denver. His interests include architectural energetics, the iconography of western Mexico, the transition from Classic to Epiclassic Jalisco, sacred spaces, remote sensing, and public archaeology. He has conducted archaeological fieldwork in New York and Jalisco and contributed to projects in Colorado, Wisconsin, and Italy.

Megan Drennan is a Cultural Resource Management archaeologist, working around the United States. She holds an MA in Archaeology/Anthropology from Northern Illinois University and a BA in Anthropology from the University of Connecticut. She has participated in research and contract excavations in the US, Sicily, and Austria, and interned at the American Museum of Natural History in New York. Her research interests include Old World architecture, the use of new digital technologies in archaeological analysis and public outreach, and potential applications of ancient technologies to present-day endeavors.

Jina Heo is an Honorary Fellow with the University of Wisconsin-Madison, where she earned her PhD in 2018. She is interested in ancient urbanism and the development of sociopolitical complexity in archaic states, particularly in East Asia. Heo's work deals with trading systems and exchange networks involving beads and other ornamental craft goods, looking at interactions between proto-historic Korea and other areas, such as China and Southeast Asia. She has worked as curator, excavator, and lecturer at several museum and university settings in South Korea and has performed extensive fieldwork throughout the country. Most recently, her fieldwork experience has extended into Vietnam.

Scott Detrich Kirk is a PhD candidate in the Department of Anthropology at the University of New Mexico where his doctoral work focuses on the development and spread of European fortifications in the Old and New Worlds over the past millennium. Scott graduated from Northern Illinois University in 2013 with an MA in anthropology. During his time at NIU, he focused on the development and spread of Islamic tableware in medieval Sicily. His field experience includes both excavation and survey in Sicily and New Mexico. Other research interests include geospatial analysis and remote sensing. He has recently published a pilot study in *Advances in Archaeological Practice* where he and several colleagues used differences in vegetation indices as a method for potential site detection.

Nam C. Kim is Associate Professor of Anthropology at the University of Wisconsin-Madison. He is interested in the emergence of early forms of cities and states, particularly in Southeast Asia. Kim's work also explores

the links between the material record and the concerns of contemporary societies, as they relate to issues such as national identity and cultural heritage management. Beyond his work on Asian archaeology, Kim's research also explores the various evolutionary and cultural dimensions of organized violence, warfare, and peacemaking throughout human history. He has performed fieldwork in several countries, most recently in Vietnam.

Michael J. Kolb is Professor of Anthropology at Metropolitan State University of Denver, and Presidential Teaching Professor Emeritus at Northern Illinois University. He has undertaken architectural labor investment studies for 30 years in both the Pacific and the Mediterranean, and has a forthcoming book to be published by Routledge, entitled: *Making Sense of Monuments: Narratives of Time, Movement, and Scale*.

Cameron H. Lacquement is an Assistant Teaching Professor at the University of Alabama. His research interests include archaeological approaches of prehistoric architecture both public and domestic. His work particularly concerns the late prehistoric Southeast, with emphasis on changes in architecture as a result of increasing complexity, experimental reconstructions, and methods of labor expenditure. Lacquement has published on his approach to energetics in *Southeastern Archaeology*.

Jerrad Lancaster is a Senior Lecturer at the University of Akron in the Department of Anthropology. He is broadly interested in archaeology of the Classical World, but more specifically the Greek colonization of the Mediterranean in the Archaic period. His current research is in the archaeological uses of unmanned aerial vehicles. This has extended to the documentation and preservation of historical and cultural heritage objects in 3D via photogrammetry.

Leah McCurdy is a Senior Lecturer in the Department of Art & Art History at the University of Texas at Arlington (UTA) and a Research Associate with the University of Texas at San Antonio (UTSA). Leah earned her PhD from UTSA in 2016 with her dissertation focused on the application of energetics and labor analysis to the ancient Maya site of Xunantunich, Belize. Leah has been excavating at Xunantunich since 2008 to collect data relevant to her research interests in ancient construction practices, cooperative labor, the intersections of monumentality and community, as well as the meaning of the ancient built environment.

Tatsuya Murakami is an Assistant Professor in the Department of Anthropology at Tulane University. He received his PhD from Arizona State University. His research focuses on the materiality of sociopolitical processes in central Mexico based on practice-based and multidisciplinary approaches. He has conducted construction experiments, materials analysis of lime plaster and cut-stone blocks, and an analysis

of lapidary objects at Teotihuacan. He is currently directing an archaeological project at the Formative site of Tlalancaleca, Puebla, Mexico, which is investigating the genesis, transformation, and decline of an early urban center and broader regional processes leading to state formation at Teotihuacan.

François Remise is an engineer, working for 34 years as a manager of building companies, with a particular interest in construction site management. Since he retired, he has been studying archaeology and art history at the Ecole Pratique des Hautes Etudes of Paris where he is now a doctoral student. He is interested in protohistorical cultures of Western Europe, and mainly in the Celtic civilization, with a particular focus on labor organization.

Richard L. Smailes is a Senior Lecturer at the Rinker School of Construction Management at the University of Florida, having earned a bachelor's degree in 1976, a master's in 1977, and a PhD in 2000. His area of research is the use of modern construction management tools and techniques to analyze the labor effort and construction time of ancient architecture. Prior to academia, he spent 20 years in the private sector performing construction management on projects including power plants, commercial projects, and residential construction. He has held a Certified General Contractor's license in Florida since 1977.

Preface

As a compilation of recent and ongoing research incorporating architectural energetics, this volume is a direct outgrowth of and expansion upon Elliot M. Abrams' seminal 1994 book entitled *How the Maya Built Their World: Energetics and Ancient Architecture*. Each author and case study presented in this volume is indebted to his work. At the 25-year anniversary of the publication of *How the Maya Built Their World*, this current volume is a celebration of Abrams' contribution to the study of ancient architecture and the field of archaeology.

Further, this volume was conceived of and preliminarily developed as a result of a symposium entitled "Architectural Energetics" at the 2016 Annual Meetings of the Society for American Archaeology in Orlando, Florida. Several of the contributors here presented in that symposium. In addition to the academic inspiration it created, the symposium engendered a sense of community among us that I hope will continue.

Leah McCurdy

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1 Massive assumptions and moundbuilders

The history, method, and relevance of architectural energetics

Elliot M. Abrams and Leah McCurdy

Introduction

All human societies, whether residing in small nomadic campsites or densely populated urban centers, create architecture. To do so involves the procurement and modification of desired materials, ultimately derived from the natural environment, and the construction of features that newly define a specific form and space, or the built environment (Rapoport 1969, 1990a; also Lawrence and Low 1990). The intellectual conception, planning and design, artistry, and scale of personal labor invested to complete such architectural works collectively represent one of the great achievements of society. As the embodiment of political and social symbolism, differential power, and cultural identity and pride, no product of the ancient human imagination and physical effort rivals that expressed in architecture.

Three specific but intertwined qualities define architecture, and especially monumental architecture, as unique among material entities. First, architecture is the most visually apparent and symbolic element of the cultural landscape. By visually projecting cultural imagery across a landscape, architectural facades conspicuously serve to promote intended symbolism in a manner unmatched by any other element of the cultural landscape.

Second, architecture tends to be built with materials selected for their durability. When earth used in architecture is packed, its density allows it to better withstand the entropic factors of nature. When builders selected stone as the raw material for structural components of architecture, they implicitly or explicitly emphasized durability and thus, longevity through architecture. Once the longevity of architecture transcended the original generation of builders, architecture became an artifact intended for future generations of occupants and observers, a characteristic appreciated today by tourists and archaeologists alike.

Finally, the unique quality of physical scale is the overriding aspect of many monumental architectural works. Unlike ceramics, clothing, or jewelry, architecture can be scaled well beyond the personal or even the pragmatic (e.g. Trigger 1990). When the size and concomitant complexity of a building transcends the construction capabilities of the household level,

architecture becomes a collective artifact of society. The potential of great physical size of the built environment magnifies the significance of the act of building in a manner unprecedented in the material world.

These unique qualities make the built environment endlessly interesting to scholars and particularly attractive to a wide range of analyses in both the social and physical sciences. Past and present architects and engineers have considered the physical, ecological, artistic, and other elements of the built environment and a considerable range of architectural theory emerged from their work (e.g. Braham 2016; Roys 1934; Mallgrave 2006; Rapoport 1973, 1990a, 1990b). In both anthropological and classical archaeology, architecture is one of the most studied elements from past societies, examined from a diverse set of perspectives (e.g. McGuire and Schiffer 1983; Lawrence and Low 1990; Bretschneider et al. 2007; Smith 2011; Burger and Rosenswig 2012).

One broad category of architectural analysis in archaeology involves discerning the specific types of labor organization that were responsible for the creation of the architectural landscape (Brysbaert et al. (eds.) in press). Regardless of whether we are considering simple houses or grand cathedrals, all stages in the building process – from design to final assembly – were planned in the context of distinct labor organizations and political economies. The consideration of increasingly large-scale architecture opens opportunities for examining elements of status or wealth, engineering skill, political power, and especially the size of the requisite labor pool.

The unique characteristics that define large-scale architecture are dependent upon the increasing scope and organizational complexity of labor. Scholarship in the realms of ancient political economies and power relations often relates to the investigation of labor control, or the extent to which certain people or groups held greater degrees of control over or access to the labor of others (Wolf 1990; also Childe 1950; Haas 1982; Price 1984; Trigger 1990). Increasingly strong and centralized labor control often correlates with other facets of centralization and developments of complexity (Brumfiel and Earle 1987; Trigger 1990; Wolf 1990, 1999). The ability to build at a large scale is filtered through the barrier of social power; in most cases only kings and emperors can commission grand monuments that command the labor of thousands of compliant laborers. There are examples of large-scale cooperative labor efforts that produced impressively sized architecture without a context of centralized political control and management (e.g. Allen 1995; Gibson 2004; Burger and Rosenswig 2012).

Architectural energetics

Often, archaeologists rely upon general nominal terms such as "monumental" when characterizing the scale of architecture. There is nothing inherently inappropriate about the term; however, its usage often leads to unproblematized or assumed implications of construction involving "massive amounts of human labor" (Bradley 2001) without a comparative basis

for "massive." Analyses that involve an interval scale based on evidenced cost estimates of time and labor advance the analysis of scale in a more comparative and interpretively effective direction. Towards these goals, when archaeologists *quantify* the number of laborers per building task for any architectural project yielding a total "cost" of construction, then we are engaging in the archaeological field of *architectural energetics*.

Architectural energetics is a methodology that explicitly seeks to quantify past architectural remains in terms of the labor force involved in construction projects, or labor "cost." Once buildings are translated into their quantified cost equivalent, archaeologists can reconstruct the organization of the labor required in construction. This is relevant to contemporary archaeology since *the scale and organization of that labor force is the most direct means of inferring political, social, and economic power relations in the archaeological past*. The anthropological significance of better understanding the transformation of various forms and expressions of power in past societies, best reflected in the quantified study of architectural scale and its time-labor equivalence, lies at the core of conducting architectural energetic analyses.

Methodology

Architectural energetics, a term coined by Abrams (1984, 1987, 1989), involves the explicit translation of any architectural project into its quantified time-labor equivalent. Time-labor equivalences serve as the basis for inferring aspects of a past society, most notably labor organization, political and social relations of power, and scales of economic specialization. All chapters in this volume provide detailed examples of the interpretive value of architectural energetic analysis. The ability to offer knowledge claims about these critical elements of a past society justifies the methodological effort required to translate the physical archaeological remains of architecture into quantified labor costs.

Energetics per se involves the quantified study of energy flow and transformation regardless of system; hence energetics can be applied in mechanical engineering, ecology, etc. (Odum 1971). Energetics applied to architecture involves quantifying the systemic flow of work expended in the construction process. Importantly, architectural energetics must be expressed in a common currency to allow for comparison of buildings, time periods, and labor investment. Energy is typically equated with cost defined by time and human effort. While the term "cost" may appear overly contemporary, it is simply used as an equivalent to expended labor. In some cases (Shimada 1978; Lacquement 2009, Chapter 8), actual kilocalories of energy are the unit of labor.

The most frequently used units in time-labor studies are the person-day or person-hour. The person-day was first used by Abrams (1984) as a replacement for the man-day typical of such studies prior to the 1980s (notably Aaberg and Bonsignore 1975; Erasmus 1965). The reason for this substitution is obvious – women as well as men are involved in construction on many different scales.

In fact, either men or women may construct houses on a family-based level and women often perform tasks in large-scale construction operations. The use of person-day also allows for the participation of children.

There are several methodological steps to operationalize architectural energetics. First, the structure being analyzed must be deconstructed into its measurable component parts. Most scholars choose to organize this deconstruction according to material and process, thus coursed masonry components are distinguished from wooden components. By doing so, we modify the observational unit of analysis from a single building to a set of articulated architectural elements. This step alters the way we imagine the completed building as it forces us to consider wall heights, roof forms, etc. in a different light. In this sense, it requires us to rebuild the structure on paper.

Second, measurements of each component of the structure must be estimated. This step is often referred to as volumetrics (Adams and Adams 2003). This may seem simple but measuring the original volume or numbers of components of an archaeological structure is an imprecise exercise. For example, the original placement of earth in Hopewell-period earthworks has often been altered through natural transforms, thus making the original volumetric measurement difficult to discern (e.g. O'Neal et al. 2005). Similarly, the wall height of most stone buildings often must be estimated based on recovered collapsed materials. Fortunately, we are not seeking perfection but rather measurements that are relatively accurate and comparative to meet the analytical goals of architectural energetic research (Abrams 1989). Often, minor components of the structure, if deemed of minimal cost, may be ignored in this step (see McCurdy 2016, Chapter 10 for discussions of when minor components retain value for energetic analyses).

The actual determination of volumes may be done through mathematical measurements derived from volumetric formulae, computer graphic mapping (Lacquement 2010, Chapter 8), or 3D virtual technologies (Drennan 2014; McCurdy 2016, Chapter 13). In various stages of the analytical process, it is necessary to convert measurements according to the units of available time-labor cost estimates; for example, a cubic meter estimate of raw material(s) often must be converted to its weight in kg.

The third step involves determining the behaviors associated with each architectural component and assigning a cost estimate for each behavior. In archaeology, this is conducted within the context of "formation processes" (Schiffer 1983), that is, the behavioral workflow necessary for the creation of any artifact. In terms of architecture, these costs generally involve procurement of the raw materials, transport of those materials to the construction site, manufacturing of components (if necessary), and the actual assembly of the building's constituent parts (see Abrams 1994). The archaeologist is responsible for explicitly stating what behaviors were deemed relevant within the construction process and the means through which specific costs assigned to that behavior were obtained. These decisions are contextual, though can be approached using some standardized measures.

For relatively simple architecture such as earthen burial mounds in the Ohio Valley, only two costs – procurement of earth and transport of earth – are essential to generate an effective total cost of construction (Bernardini 2004; Abrams and LeRouge 2008; Davis et al., Chapter 7). Other researchers have considered the tamping of earth (e.g. Lacquement 2009, Chapter 8; Milner et al. 2010; Xie et al. 2015). In cases of larger architecture incorporating more materials, such as Mesoamerican palaces and temples, over 20 individual costs can be identified and incorporated into analyses (Abrams 1984; McCurdy 2016; Murakami 2015).

This step involves the key methodological question in architectural energetics – *how* do we confidently generate a reliable and contextually relevant cost estimate per construction task for a past behavior? The only answer is by observing and timing people while they are performing various construction behaviors in specific settings (see also Turner, in press). These times per behavior have been recorded in historic and ethnographic literature and, most currently, in the present context of replicative archaeology wherein behaviors are structured and timed specifically by the archaeologist. Any replicative timed observations must be guided by both the archaeological and ethnographic record and be designed to most closely parallel the past behavior (Abrams 1989).

It has been recognized (Abrams 1989, 67) that the cost per activity or work rate will vary according to physical factors such as soil type and climate as well as social factors such as gender, economy of scale, incentive, and the psychology of work. Thus, a standard or average cost per activity may seem illusionary. However, there are discernible ergonomic ranges for human activities. When people are asked to perform a construction task under controlled circumstances, a consistent and realistic range of costs are obtained that can be averaged to generate a useable time–cost estimate.

As a case in point, several cost estimates for digging earth, perhaps the most quantified of construction activities, have been compiled (see Table 1.1). Though not exhaustive, we see the following average costs (based on a five hour work day): 1.84 m^3/p-d (median) for dense soils in the Ohio Valley (Milner et al. 2010), 2.1 m^3/p-d for silt and clay loam in the eastern US (adjusted for the use of metal shovels; Gillette 1903), 2.13 m^3/p-d and 4.25 m^3/p-d in India (rates varying by climate; ECAFE 1957), 2.6 m^3/p-d for sandy soil of west Mexico (Erasmus 1965), 3.3 m^3/p-d for loam soil of central Italy (DeLaine 1997), and 2.94 m^3/p-d and 3.65 m^3/p-d (median costs using bone and stone tools, respectively) for average density soils in southeastern China (Xie et al. 2015). These independently generated cost estimates vary according to knowable conditions, such as soil type, and are conspicuously non-random. Thus, they can serve as useful estimates, which is all that is methodologically required.

Finally, once a cost estimate is determined for each task by the archaeologist and each of these costs is matched against the appropriate volume or numbers of components per structure, a total cost estimate for construction

Table 1.1 Compendium of time-labor costs (or work rates) used in architectural energetic analyses

Construction operation/ task	*Context derived*	*Work rate*	*#hr work day*	*Citation*	*Comments*
Procurement					
stone quarrying – limestone	western Mexico	0.46 m^3/p-d	5	Erasmus 1965	
stone quarrying – limestone	central Guatemala	0.03 m^3/p-d	U	Woods and Titmus 1996	blocks of 75 cm x 50cm x 50cm
stone quarrying – tuff	western Honduras	0.41 m^3/p-d	5	Abrams 1994	
stone quarrying – tepetate volcanic tuff	central Mexico	0.9 m^3/p-d	5	Murakami 2015 modified after Abrams 1994	
stone quarrying – basaltic breccia	central Mexico	0.66 m^3/p-d	5	Murakami 2015 modified after Abrams 1994	
earth digging – dense soils	Ohio Valley	1.64 m^3/p-d - 1.84 m^3/p-d	5	Milner et al. 2010	dug with chert hoe
earth digging – dense silty loam	Ohio Valley	1.7 m^3/p-d	5	Davis et al. Chapter 7	averaged from Milner et al. 2010
earth digging – dense soils	Ohio Valley	1.45 m^3/p-d	5	Hammerstedt 2005	
earth digging – sascab (marl)	western Mexico	2.0 m^3/p-d	5	Erasmus 1965	
earth digging – silt and clay loam	North America	2.1 m^3/p-d	5	Gillette 1903	adjusted for use of metal shovel
earth digging	India	2.13 m^3/p-d	5	ECAFE 1957	rates vary due to climate
earth digging	India	4.25 m^3/p-d	5	ECAFE 1957	rates vary due to climate
earth digging – sandy soil	western Mexico	2.6 m^3/p-d	5	Erasmus 1965	

earth digging – loam soil	Italy	3.3 m^3/p-d	5	DeLaine 1997	
earth digging – chalk	southern England	2.55 m^3/p-d	5	Startin 1982	
earth digging – silt loam with stone tool	southeastern China	15.63 m^3/p-d – 0.7 m^3/p-d (median = 3.65 m^3/p-d	5	Xie et al. 2015	experiments conducted in modern rice field; costs desilt loam penetration resistance (PR) value
earth digging – silt loam with bone tool	southeastern China	20.00 m^3/p-d – 0.36 m^3/p-d (median = 2.94 m^3/p-d	5	Xie et al. 2015	experiments conducted in modern rice field; silt loam penetration resistance (PR) value
earth digging	southeastern US	kJ = M x (2.87 kJ/1 kg)	U	Lacquement 2009	M=mass of mound
cobble collection	western Honduras	7200 kg/p-d	8	Abrams 1994	
tree felling	general	20 cm diameter	25 min	Hammerstedt 2005	To cut and trim generic tree species
wood for lintels or straight segments	unknown	7 lengths/3.76 p-d	8	McCurdy 2016 based on Carneiro 1979a	1 lintel length = 3m x 1m x 0.2m
Transport					
any material	no context	p-d = m^3/(Q x (1/(L/V + L/V')) x H)	5	Aaberg and Bonsignore 1975 based on ECAFE 1957	Q=quantity per load (needs weight conversion); L=distance; V=velocity (loaded) 3km; V'=velocity (unloaded) 5km
earth	Mexico	3.17 m^3/p-d	5	Erasmus 1965	50 m distance
earth	Mexico	1.76 m^3/p-d	5	Erasmus 1965	100 m distance
stone	Sicily	5.6 m^3/p-d – 6.1 m^3/p-d	12	Lancaster, Chapter 5	25 m distance

(*Continued*)

Table 1.1 Continued

Construction operation/ task	*Context derived*	*Work rate*	*#hr work day*	*Citation*	*Comments*
any material	western Mexico	1 m^3/9.023 p-h	8	Smailes 2011 modified after Erasmus 1965	
transport adobes	Andean region	1 m^3/7.8 p-h	8	Smailes 2011	range: 1 m^3/6.7–9 p-h
load into baskets ("and carrying")	Italy	1 m^3/0.06 p-d	U	DeLaine 1997 citing Pegoretti I: 157	
raising soil from foundations > 1.6m deep	Italy	1 m^3/0.018 p-d	U	DeLaine 1997 citing Pegoretti I: 243	
raising materials	Italy	1 m^3/0.012(h-1) p-d	U	DeLaine 1997 citing Pegoretti I: 144	h=height of wall
carry over 105 m	Italy	1 m^3/0.075 p-d + 0.0047 p-d/trip	U	DeLaine 1997 citing Pegoretti I: 157	105m = maximum transport distance from depot; half the building site (from depot to center of site)
earth transport	southeastern US	kJ = ((L x 0.35/L) + (L x 0.22/L)) x (M/11 kg)	U	Lacquement 2009	L=distance; M=mass of mound
Manufacture					
dressed masonry – tuff	western Honduras	0.086 m^3/p-d	8	Abrams 1994	average dimensions: 30cm x 21cm x 36cm or 27cm x 18cm x 40cm
finish block masonry – volcanic	central Mexico	0.084 m^3/p-d	8	Murakami 2015	
"facing stones (general)"	central Mexico	0.13 m^3/p-d	8	Murakami 2015	
"facing stones (talud-tablero)"	central Mexico	0.11 m^3/p-d	8	Murakami 2015	
adobe bricks	central Mexico	1.1 m^3/p-d	8	Murakami 2015	

adobe bricks	Andean region	1.1 m^3/p-d	8	Smailes 2011	range: 1 m^3/5.2–7.5 p-h; bricks approximately 10 cm x 25 cm x 35 cm
adobe bricks	Germany	0.6 m^3/p-d – 1.3 m^3/p-d	U	Remise, Chapter 4	range based on scale of project
adobe bricks	Sicily	0.7 m^3/p-d – 4.0 m^3/p-d	12	Lancaster, this volume	
rough cobbles	western Honduras	0.86 m^3/p-d	8	Abrams 1984b	
mud preparation	central Mexico	2.13 m^3/p-d	8	Murakami 2015	
crushed tepetate	central Mexico	0.08 m^3/p-d	8	Murakami 2015	
crushed breccia	central Mexico	0.12 m^3/p-d	8	Murakami 2015	
clay amalgam mixing	central Mexico	1.83 m^3/p-d	8	Murakami 2015	
lintel cutting	western Honduras	1 m^2/p-d	8	Abrams 1984b	
"sawing timbers"	Italy	1 m^2/0.2 p-d	U	DeLaine 1997 citing Pegoretti II: 291	"average value per pair of sawyers"
simple sculpture	western Honduras	321 cm^2/p-d	8	Abrams 1994	
complex sculpture	western Honduras	89 cm^2/p-d	8	Abrams 1994	
plaster manufacture	western Honduras	1 m^3/43.9 p-d	8	Abrams 1994	includes 1) cutting greenwood; 2) transporting timber; 3) stacking trees into heaps; 4) excavating limestone; 5) preparing limestone by cracking into smaller segments; 6) transporting and depositing stone onto the heap
lime burning ("lime production")	central Mexico	0.03 m^3/p-d	8	Murakami 2015	

(*Continued*)

Table 1.1 Continued

Construction operation/ task	*Context derived*	*Work rate*	*#hr work day*	*Citation*	*Comments*
slaking lime ("per volume of quicklime")	Italy	1 m^3/1.2 p-d	U	DeLaine 1997 citing Pegoretti II: 131	
render mixing	central Mexico	0.22 m^3/p-d	8	Murakami 2015	general rate and does not account for distinct render recipes
mixing mortar, foundations	Italy	1 m^3/0.55 p-d	U	DeLaine 1997 citing Pegoretti II: 144	
mixing mortar, walls	Italy	1 m^3/0.7 p-d	U	DeLaine 1997	
"fabricate roof panels"	Andean region	1 panel/29.8 p-h	8	Smailes 2011	roof panels constructed over adobe buildings of Chimu; range: 1 panel/23.9–36.5 p-h
Construction (**Assembly**)					
"digging in clay and throwing behind"	Italy	1 m^3/0.15 p-d	U	DeLaine 1997 citing Pegoretti I: 155	digging for sub-surface construction
"digging foundations and throwing out ≤ 1.6 m^2 deep"	Italy	1 m^3/0.14 p-d	U	DeLaine 1997 citing Pegoretti I: 241–245	digging for foundations
"digging foundations and throwing out > 1.6m^2 deep"	Italy	1 m^3/0.15 p-d	U	DeLaine 1997	
"shoring foundations" (skilled)	Italy	1 m^3/0.15 p-d	U	DeLaine 1997	
"lay foundations"	Italy	1 m^3/0.35 + 0.01(d-1) p-d	U	DeLaine 1997 citing Pegoretti II: 144	d=depth of foundation
"lay brick and core for walls" (skilled)	Italy	1 m^3/4.18 + 0.13(h-1) p-d	U	DeLaine 1997 citing Pegoretti II: 144–145	h=height of wall

"lay brick and core for walls" (unskilled)	Italy	1 m^3/(4.18 + 0.13(h-1)) x 0.5 p-d	U	DeLaine 1997 citing Pegoretti II: 144–145	h=height of wall
compacting earth	southeastern US	kJ= M x (1.44/amount of soil kg/hr)	U	Lacquement 2009	M = mass of mound
scaffolding, erect over façade surface (skilled)	Italy	1 m^2/0.021 p-d	U	DeLaine 1997 citing Pegoretti II: 6–7	
scaffolding, erect over façade surface (unskilled)		1 m^2/(0.021) x 2 p-d	U	DeLaine 1997	
scaffolding, uprights (skilled)	Italy	1 upright/0.25 p-d	U	DeLaine 1997	
scaffolding, uprights (unskilled)	Italy	1 upright/(0.25) x 4 p-d	U	DeLaine 1997	
erect centering (small or simple vault)	Italy	1 m^2/0.1 p-d	U	DeLaine 1997 citing Pegoretti II: 209	
erect centering (large or complex vault)	Italy	1 m^2/0.2 p-d	U	DeLaine 1997	
masonry (core & finish masonry) – tuff	western Honduras	0.8 m^3/p-d	8	Abrams 1984b, 1994	includes multiple components of the overarching task including applying mortar, setting blocks, discuss procedures, minor re-chipping to make blocks suitable for specific wall conditions, guideline installation
"retaining wall"	central Mexico	3.5 m^3/p-d	8	Murakami 2015	
adobe walls	Andean region	1 me/9.9 p-h	8	Smailes 2011	range: 1 m^3/8.7–11 p-h

(*Continued*)

Table 1.1 Continued

Construction operation/ task	*Context derived*	*Work rate*	*#hr work day*	*Citation*	*Comments*
"walls" (finish masonry)	central Mexico	1.06 m^3/p-d	8	Murakami 2015	
talud	central Mexico	1.84 m3/p-d	8	Murakami 2015	
talud-tablero	central Mexico	2 m3/p-d	8	Murakami 2015	
"erect roof panels"	Andean region	1 panel/4 p-h	8	Smailes 2011	roof panels constructed over adobe buildings of Chimu; range: 1 panel/13–19 p-h
staircase	central Mexico	0.76 m3/p-d	8	Murakami 2015	
construction cell (cobble walls)	central Mexico	3.5 m^3/p-d	8	Murakami 2015 (see McCurdy 2016)	
construction cell floors	north Honduras	4 m^3/p-d	U	Carrelli 2004 "wet-laid fill"	
fill (major pyramids)	central Mexico	6.7 m3/p-d	8	Murakami 2015	
fill (other structures)	central Mexico	3.7 m3/p-d	8	Murakami 2015	
fine fill and superstructural wall fill	western Honduras	4.8 m^3/p-d	8	Abrams 1984b	Derived volume from m^2 of vertical/battered finished surfaces by 0.1m depth.
cobble subflooring	western Honduras	9.6 m^2/p-d	8	Abrams 1984b	
plaster application (walls)	central Mexico	10.42 m^2/p-d	8	Murakami 2015	
plastering – applying a base coat	central Mexico	19.27 m^2/p-d	8	Murakami 2015	
plastering – smoothing	central Mexico	45.1 m^2/p-d	8	Murakami 2015	
plastering – polishing	central Mexico	45.1 m^2/p-d	8	Murakami 2015	
plastering (all steps)	western Honduras	80 m^2/p-d	8	Abrams 1984b, 1994	derived from modern construction reports
plastering over adobe walls and floors	Andean region	1 m^3/0.83 p-h	8	Smailes 2011	range: 1 m^3/0.57–0.98 p-h

Amalgam application (walls)	central Mexico	6.37 m^3/p-d	8	Murakami 2015	
decorative stucco application	western Honduras	1 m^3/14.3 p-d	U	Carrelli 2004 "deep-relief plaster decoration"	
painting (solid color)	central Mexico	45.10 m^2/p-d	8	McCurdy 2016 based on Murakami 2015	
painting (decorative color)	eastern Guatemala	1.05 m^2/p-d	8	McCurdy 2016 based on Hurst 2009	
wattle-and-daub building	western Honduras	p-d = –13.838 + 1.832 (m^2)	8	Gonlin 1993; Abrams 1994	this formula incorporates all operations
champa building	western Honduras	p-d = (–13.838 + 1.832 (m^2))/10	8	Abrams 1994	
Supervision					
Supervising laborers	Western Europe	10%–25% of total cost	N/A	DeLaine 1997; Lancaster, Chapter 5	
Supervising laborers	Germany	5%–10% of total cost	N/A	Remise, Chapter 4	
Supervising laborers	N/A	1 supervisor/4 – 8 laborers	N/A	McCurdy, Chapter 10	Based on Johnson 1982 "scalar stress" model

p-d = person-day/p-h = person-hours; U= unknown

of that building can be mathematically calculated. This final number is necessarily an estimate since the measurement of component volumes and the labor cost per activity are themselves estimates. In fact, one can never know the "true" cost of a structure without written documentation.

There are several additional methodological observations concerning architectural energetics. First, data are limited concerning many of the site-specific cost estimates relating to construction activities. These gaps must be filled to advance this approach. However, it is important to remember that lack of data in no way logically nullifies a methodology. It simply magnifies the need for more data, which in many cases effectively becomes a sample size issue. Further, architectural energetics is an evolving scholarly approach that improves with practice and application. As more applications and additional site-specific costs are obtained, improvements in the standardized use of this method will be realized.

We view this method as too analytically valuable to discard despite its imperfections, and we should not set a benchmark for architectural energetics that few, if any, archaeological analyses could meet. Archaeologists do not balk at pursuing important analyses despite an awareness of the inherent imprecision of data. If that were the case, then archaeologists would never conduct settlement surveys designed to reconstruct population size estimates, numbers that themselves rely on analogous baseline estimates.

Finally, the process of conducting architectural energetic analyses during excavations has the potential of sharpening the quality of those excavations since it requires the excavator to thoughtfully consider the amount and origin of each raw and finished material. Questions that may not have been asked may arise in the process of operationalizing construction. This may lead to more standardized and expanded datasets.

From an interpretive point of view, the process of conducting architectural energetics offers a view into past construction processes. Through such detailed analyses, we can envision the construction project through the eyes of an ancient builder. Once we have rebuilt the structure on paper (as above), we then "reverse engineer" the planning originally involved in creating the structure(s) of interest. We are able to step even further into the shoes of ancient builders to consider in incredible depth the parameters of constructing in particular environments and time periods. This technical lens can then be married with the large-scale questions of labor organization, political economy, and sociopolitical power that architectural energetics is particularly poised to address.

Historical outline of architectural energetics: moundbuilders and beyond

Numerous studies of comparative labor costs in the field of construction (e.g. Gillette 1903, 1904; ECAFE 1957) have provided useful energetic cost data, especially those involving low-technology human labor. These studies,

however, were not designed specifically to address research questions in archaeology. Here we present a general outline of trends relating to the long history of quantified architectural labor studies specifically within archaeology.

There has long been a compelling curiosity concerning the quantification of archaeological ruins. One of the first US archaeologists to apply labor estimates to generate a cost for construction to explicitly address an archaeological research question was Fowke (1902). A pioneering archaeologist and geologist who worked in Ohio and elsewhere, he observed one of the largest earthen mounds in Butler County in western Ohio. By recording in a very general manner the work rates of his laborers carrying bushels of maize measured against the volume of the earthwork, he suggested that "… there is no need for supposing a great number of inhabitants to account for the creation of even the largest earthworks" (1902, 81). In doing so, he offered one of the earliest scientific refutations to the idea that non-indigenous "moundbuilders" were responsible for earthwork construction. Instead, he inferred from his crude estimates that fewer people were required for their construction than previously imagined and thus, these past civic architectural projects could have been accomplished by a relatively small number of local Native Americans. Interestingly, the research by Fowke did little to influence public opinion concerning the presumed and exaggerated presence of non-indigenous builders (Milner 2004, 16).

During the subsequent decades of archaeological research, only sporadic architectural labor analyses were conducted (e.g. Curwen 1926; Morris et al. 1931). These generally related to ancient building technology. This coincides with the phase in Americanist archaeology that focused more on site and artifact descriptions, general chronology, and regional classifications, summarized as culture history (Willey and Sabloff 1993).

Beginning in the 1960s, significant interest in cultural systems, quantified studies, and a focus on energy flow led to more directed research on architecture and labor. Several preliminary applications were conducted (Kaplan 1963; Heizer 1966; Reed et al. 1968; Aaberg and Bonsignore 1975), most involving the quantification of a single large structure. Much of this initial research was designed to classify past societies within ethnological categories of chiefdom or state. These and other studies, however, initiated the quantified approach to architecture and labor.

Importantly, Erasmus (1965) conducted experiments involving earth digging and moving in Las Bolsas, Mexico, and stone quarrying and moving in Tikul, Yucatán, Mexico. Based on those more explicit labor costs, he generated a cost for the construction of the entire Maya site of Uxmal. His rates of work had a great influence on subsequent research and, in some cases, are still used today (see Table 1.1). At roughly the same time, researchers involved in experimental earthwork construction in England (Atkinson 1961; Jewell 1963) were generating preliminary labor costs comparable to those derived by Erasmus. These cost estimates were later applied to studies

of the construction of barrows and causeway enclosures in that region (Renfrew 1973; Startin 1982).

The application of construction labor costs as a means of assessing relative power was crystallized and refined in the 1980s and 1990s within anthropological archaeology in large part by Abrams. Although prior scholars conducted labor estimate analyses on archaeological construction efforts, Abrams gave it a name – architectural energetics (1984, 1987, 1989). By doing so, he created a label and thus a cognitive identity for such research. More significantly, Abrams' application of architectural energetics transcended previous research in three important ways.

First, Abrams excavated at the Maya center of Copán, Honduras, as a member of the Copán Project Phase II. This project was designed to horizontally excavate the full range of household types in courtyards adjacent to the Main Center. That excavation methodology provided detailed architectural data on the full spectrum of houses; thus, the comparative labor analysis went beyond the focus on a single large structure. This intra-societal analysis transcended classifying the Copán polity into an ethnological category of political complexity (Abrams 1984).

Second, Abrams was not only privy to the collective excavation skills of other project archaeologists whose efforts provided the broader sample size, but also benefited from the outstanding skills and depth of knowledge of Rudy Larios, an archaeological architect and conservator who was responsible for the rebuilding of the excavated structures. The required rebuilding of architecture at Copán provided the opportunity for Abrams to conduct a broad set of replicative experiments specifically designed to quantify many of the steps in the construction process.

Third, Abrams had the opportunity to conduct an ethnographic survey of 23 Copán families living in wattle and daub houses. By interviewing these house owners and builders, a richer set of data and insights emerged through analogy concerning the construction processes conducted by past inhabitants of the valley. By obtaining cost estimates through interviews of contemporary Copanecos, a logical progression of cost estimates, from low-energy commoner wattle and daub structures to high-energy elite stone structures, emerged. This research at Copán was presented in *How the Maya Built Their World* (Abrams 1994), which established architectural energetics as a viable approach to analyzing architecture.

An important expansion beyond this initial application of architectural energetics at Copán was the research by Nancy Gonlin (1993; also Webster and Gonlin 1988). Gonlin used the cost estimates generated by Abrams to quantify labor costs of lower-range structures at Copán. Thus, she strengthened the approach by further validating the continuum of labor estimates across Copán society.

Research in the Maya area continued this architectural approach at sites such as Sayil (Carmean 1991), Tikal (Webster and Kirker 1995), and Palenque (Abrams 2001). At the same time, architectural energetic

applications in such areas as the Ohio Valley (Shryock 1987; Mainfort 1989), Hawaii (Kolb 1994, 1997), and Sardinia (Webster 1991) continued to support and expand upon the methodology.

Soon after these and other efforts, DeLaine (1997) established architectural energetic research within classical archaeology. Her use of building costs from historic records applied to the detailed measurements of the baths commissioned by the Roman emperor Caracalla supported the energetic approach. Her work inspired comparable applications within the classical world (e.g. Fitzsimons 2011; Pakkanen 2013).

With the establishment of architectural energetics in both anthropological and classical archaeology, four general trends followed, leading to the present volume. First there has been a broadening of the diversity of geographic extent of the general approach to include such areas as Vietnam (Kim 2013), China (Xie et al. 2015), Eurasia (Pickett et al. 2016), Sweden (Artursson et al. 2016), Teotihuacán (Murakami 2015), the Olmec region (Cyphers and Zurita-Noguera 2012), and the Southeastern United States (Lacquement 2009; Kidder 2012). This geographic expansion has been achieved by a collection of scholars, many of whom publish in non-English speaking venues. We acknowledge that our review in this chapter is biased towards English speaking scholarship. This volume as a whole incorporates a number of scholars who reference and produce non-English works. Thus, we hope that the volume as a whole represents energetics scholarship adequately.

Second, some studies (Abrams 1998; Abrams and Bolland 1999; McCurdy 2016; Smailes 2011, Chapter 11) applied systems management models to actualize the construction process. This economic systems approach brought us closer to understanding labor dynamics and management within the construction process itself. Third, studies led to a better understanding of the emergence of economic specialists, such as sculptors, painters, and tool producers, within the construction process (Abrams 1987; Murakami 2015; McCurdy 2016). Finally, some research has specifically generated behavioral cost estimates in new geographic areas and with new technologies (e.g. Hammerstedt 2005; Milner et al. 2010, Osenton 2001; Xie et al. 2015). These and other research efforts directed at generating standardized and comparative region-specific cost estimates for archaeological structures continues to strengthen the architectural energetic approach. With this in mind, Table 1.1 – necessarily a work in progress – represents an initial step towards consolidating many of the current cost estimates per construction activity from studies around the world.

Chapters in this volume

The chapters in this volume constitute a variety of analytical expansions and global explorations of architectural energetics. We organize the chapters geographically, though there are many methodological threads that link chapters throughout the volume. As a whole, the authors are united in

exploring how architectural energetics can serve archaeology in the investigation of questions about social complexity, power relations, political economy, and labor organization of ancient groups across the globe.

In Chapter 2, Nam C. Kim and Jina Heo examine specific cases from Vietnam and South Korea where recent fieldwork at major settlements provides a basis for producing energetic models to evaluate hypotheses related to incipient states. The authors consider various contributing factors that fomented the consolidation of political authority in these respective areas, highlighting energetic requirements for a range of large-scale constructions, including earthworks, canals, and ditches. Energetic calculations, combined with chronological evidence and information from extant textual sources, hint at the existence of societies with high degrees of centralized, political control over labor and other vital resources. Thus, Kim and Heo illustrate pathways to emergent states in these two regions.

Chapter 3 turns our attention to ancient Egypt. Megan Drennan and Michael J. Kolb calculate the labor costs in the construction of the Karnak Temple Complex, and specifically the precinct of Amun, which was aggrandized by pharaonic architectural attention over a span of 2,000 years. Drennan and Kolb demonstrate that the variables of time, warfare, and the centralization of the government strongly correlated with monumental building episodes at Karnak. The results indicate that rulers with greater sociopolitical power expressed it through their successful building programs at Karnak and that such efforts served as a justification for their authority, central role, and military actions.

François Remise, in Chapter 4, applies architectural energetics to mudbrick fortifications and funeral mounds constructed during the first Iron Age, between 600 and 540 BCE, by the ruling elite of the Celtic community at Heuneburg in southern Germany. This study demonstrates the scale of labor available for the construction of a unique set of structures, never before investigated using architectural energetics. Remise also focuses on refining the analytical precision and effectiveness of cost measures associated with transportation of materials.

In Chapter 5, Jerrad Lancaster applies architectural energetics to early Archaic residential structures and fortifications on the island of Sicily beginning with the initial colonization from Syracuse. The quantification of these construction efforts provides insights into the process of colonization from a practical perspective. Lancaster's work explores the community action required of nascent populations and eventually the efforts needed to defend such populations in the face of conquest. This study represents distinct and archaeologically informed means to provide nuance to generalized narratives of colonization in the Mediterranean and across the world. Applying architectural energetics opens the analytical possibilities to a nuanced understanding of community decision making and collective action.

To continue explorations of Sicilian archaeology and history, Michael J. Kolb, Scott Detrich Kirk, and William M. Balco examine the variability

in medieval castle architectural labor mobilization to characterize political and economic change across Sicily in Chapter 6. By creating an architectural wealth hierarchy in the context of Sicilian aristocratic society and land tenure systems between the eleventh and seventeenth centuries, they argue that large Norman castles represent "founding citadels" used to project territorial claims and signal a change in the island's ruling class.

Moving to the Americas, Jamie L. Davis, Jarrod Burks, and Elliot M. Abrams in Chapter 7 use photogrammetry to generate the volume of Serpent Mound, an iconic ancient earthen construction project in the Ohio Valley. Labor costs applied to its construction indicate a high amount of labor relative to other contemporary construction projects. This quantification yields insights into later Hopewellian construction projects and the value of investigating non-state sociopolitical contexts. The authors detail their photogrammetric methodology to highlight its usefulness in improving efficiency and work flow of energetic analysis.

In Chapter 8, Cameron H. Lacquement quantifies the human energy expended in earthen monumental construction at the Moundville polity in west central Alabama. Based on his energetic study of earthen mounds, which reformulates the unit of labor from person-hours to kilojoules, Lacquement suggests that the elite allotted labor and resources from the entire polity to build some earthen mounds while smaller kin-based groups were responsible for building many other earthen constructions. His study broadens our understanding of labor "allocation" and suggests ways to problematize strictly top-down views of labor organization.

In Chapter 9, Anthony James DeLuca examines the construction of unique circular ceremonial temples in the Tequila Valleys region of Jalisco, Mexico, during the Late Formative to Classic periods (300 BCE to 450/500 CE). This represents the first architectural energetics research applied to these circular temples, particularly Circle 2 at the site of Los Guachimontones. Due to the size of the temple and its central location in the Tequila Valleys, DeLuca argues that Circle 2 may represent an upper limit of elite labor control, providing the basis for inferring the structure of labor organization and, in turn, political organization in this region.

Turning to the Classic Maya in Chapter 10, Leah McCurdy views labor investment not from the position of the elite but rather from that of the laborers. Specifically, McCurdy considers the common laborers' physical and social investment as members of monumental construction projects and the impact that participation in such projects may have had in their lives. She proposes to "people" the labor invested in monuments and considers the personal implications of large-scale cooperative labor within complex societies through the quantification of El Castillo acropolis at Xunantunich, Belize.

Richard L. Smailes, in Chapter 11, employs industry standard estimating practices to calculate the labor requirements for the monumental adobe architecture of Ciudadela Rivero at the site of Chan Chan, Peru, built by the Chimú c. 1400 CE. Smailes' application of critical path method along with

probabilistic scheduling provides researchers the means to estimate the construction time of ancient architecture. This allows archaeologists to study the data in dynamic terms and to simulate the effects of various construction and labor organization strategies in their cultural context through multiple what-if scenarios concerning how much labor was deployed and how long the construction processes may have taken.

In Chapter 12, Tatsuya Murakami expands the scope of architectural energetics through the comparison of the sites of Teotihuacán, Mexico, and Copán, Honduras, at multiple scales of social interaction. Murakami examines diachronic changes in power relations at four different analytical scales: the absolute and relative power of the state, relations among state elites/institutions, state-subject relationships, and relations among subjects. Through these multiscalar comparisons between these two major centers, Murakami demonstrates similarities and differences in the trajectory of changing power relations embodied by architecture.

To conclude the volume, the coeditors discuss the future of architectural energetics and present a vision for continued expansions. The previous chapters are reviewed in the context of addressing the connections and distinctions evident in methods and themes as applied in different archaeological contexts. The future of the methodology is considered in the context of comparative collaborations and current technologies available to archaeologists. The value of the compendium of time-labor estimates (see Table 1.1) and the potential for comparative studies to trace power and labor within distinct cultural areas is discussed. Further, innovations to architectural energetics possible through 3D and virtual technologies are detailed.

Acknowledgments

This chapter is the culmination of decades of work in this field. We acknowledge all those who have contributed to the development of architectural energetics in archaeology. In particular, we thank all volume contributors, Liye Xie, Ann Brysbaert, and an anonymous reviewer for providing comments on our introduction.

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2 Built environments and social organizations

A comparative view from Asia

Nam C. Kim and Jina Heo

Introduction

All human societies create architecture, and such constructions can embody and reflect politics, power, identity, and many other dimensions of societies (Abrams and McCurdy, Chapter 1). When these forms of architecture are expressed on very large scales, aspects of social cooperation become all the more apparent. Significant here is the characterization of construction as "social," since such buildings require the collaboration of multiple individuals, especially if we consider those constructions deemed "monumental." The human capacity for social cooperation has resulted not only in social organizations of exceedingly large scale, but also in corresponding forms of modified landscapes and architecture. For archaeologists interested in how the material record can shed light on past lifeways, cultural practices, and social configurations, the remnants of architectural expression can offer key insights.

Decades ago, Elliot Abrams (1984) provided innovative methods for the cross-cultural comparison of labor costs in architecture. These methods provide researchers with systematic and quantifiable ways to consider how labor and resources might be organized within societies, and how identities, statuses, and political interactions might be negotiated. Over recent decades, the work of Abrams and others (e.g. Abrams 1994; Abrams and Bolland 1999) has not only furnished and refined approaches for addressing the construction of monumental architecture but has also provided new datasets for analyzing local cultural trajectories of change across case studies separated by time and space. This has been particularly so for the evaluation of large-scale, sociopolitically complex societies typically referred to as "states" or "civilizations."

This chapter contributes to these ongoing research efforts by offering data from parts of Asia that have been relatively less studied by Western scholars. Despite mounting datasets from archaeological sites in Northeast and Southeast Asia, corresponding cases garner less attention in Western scholarship than research undertaken in areas such as the Near East, Mesoamerica, South Asia, and East Asia. Indeed, the Asian continent is

expansive, but most theoretical scholarship for the archaeological study of ancient civilizations and complex societies to date has largely focused on emergent Chinese and Indian civilizations, with some attention placed on the Angkorian civilization. The aim of this chapter is to supplement these previous studies with case studies from Southeast and Northeast Asia, from present-day Vietnam and South Korea, respectively. Described in this chapter are two specific archaeological sites that we have selected given some interesting parallels in contexts and trajectories of cultural change, namely the Co Loa site (Vietnam) and the Pungnap-toseong site (S. Korea). In addition to being marked by monumental constructions of earthen ramparts, both sites were situated along frontiers shared with expanding, imperial polities of emergent China. Hence, comparison of the two cases not only provides new data from Asia, but also insights about frontier relations and processes of state formation.

The Co Loa case of northern Vietnam's Red River Delta

A consideration of the underpinnings of Vietnamese civilization requires engagement with the local cultural and historical trajectories and development in the Red River Valley and Delta regions in the northern reaches of present-day Vietnam. The area's pre- and proto-historic material record, particularly during the Dongson Culture period (c. 600 BCE – 200 CE), provides important data during a crucial period of momentous sociopolitical change. Such changes are reflected by differentiation in status and wealth within various communities, as indicated by mortuary data from early Dongson sites. By the third century BCE, certain segments of the region's population garnered sufficient power to consolidate and centralize political authority, which culminated in the emergence of the Co Loa settlement, the center of the Co Loa polity (Kim 2015). Co Loa is by far the largest of all contemporaneous sites of the Red River Valley region and one of the earliest forms of city for Southeast Asia.

Covering an area of approximately 600 hectares, the Co Loa settlement is situated some 17 km north of present-day Hanoi's city center. In various states of disrepair, much of the ancient city's monumental system of earthen ramparts still remains standing. These ramparts are part of an extensive system of embankments, moats, and ditches (see Figure 2.1). This rampart system, standing 3 to 10 m in height depending on location, consists of three enclosures, with the outermost curtain (Outer Wall) measuring approximately 8 km in circumference. Measuring approximately 6.5 km and 1.65 km in circumference, respectively, are the Middle and Inner Walls (Nguyen and Vu 2007).

For decades, historians and archaeologists have debated the conditions under which the site and its system of enclosures were first constructed, relying primarily on Sinitic textual accounts and Vietnamese oral traditions (O'Harrow 1979). At the crux of such debates was the cultural identity

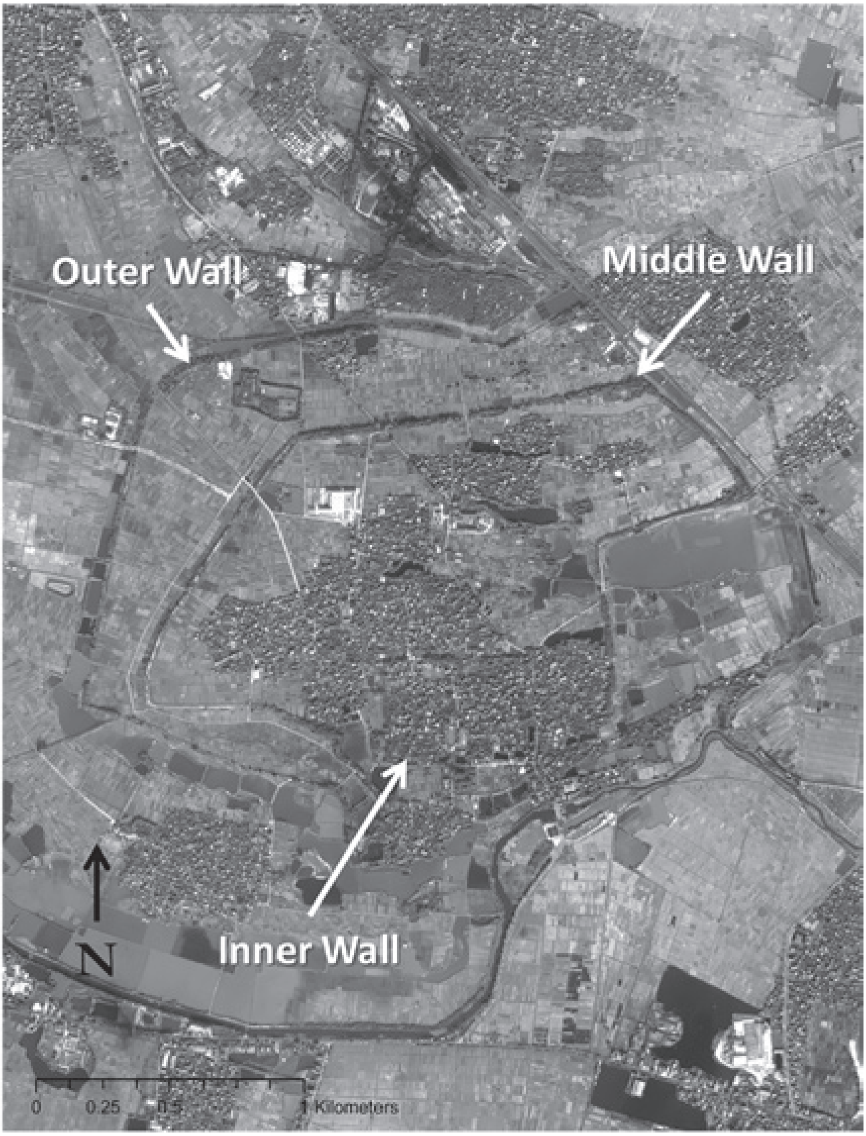

Figure 2.1 Satellite photograph of the Co Loa settlement (image provided by Digital Globe and ArchaeoTerra)

of the society responsible for founding Co Loa and constructing its ramparts, and whether the constructions are associated with local inhabitants or foreign intruders. Scholars have long wondered whether the city and its monumental constructions were built either by the Han Empire after solidification of imperial control of the region (c. first century CE), or by

local indigenous societies before Han annexation. Not surprisingly, Sinitic textual accounts suggest that the Empire encountered an indigenous, local population of barbarians devoid of agricultural, metallurgical, and political sophistication (Higham 2014; O'Harrow 1979; Taylor 2013). In contrast, Vietnamese traditions, folklore, and textual accounts describe the emergence of powerful indigenous kingdoms before Han arrival, maintaining that Co Loa functioned as the capital of a Vietnamese or proto-Vietnamese kingdom during the third century BCE (Taylor 2013). These conflicting depictions of lifeways are problematic, as some may have been colored by imperial bias, national pride, and reliance on accounts subject to change as they were passed down over millennia. As such, archaeological data are essential for clarification.

The archaeological record indicates continuous habitation in the overall area for some 4,000 years, since the late Neolithic (Lai 2014). Unfortunately, relatively little settlement archaeology has been performed at Co Loa because of preservation and accessibility issues. However, recent field investigations of the rampart system and areas within the Inner Wall have provided data pertinent to the chronology and construction processes of the settlement (see Kim 2013, 2015; Kim et al. 2010; Lai 2014). These data, particularly those associated with the rampart system, can aid in reconstructions that can help researchers to address the aforementioned debates, as well as to help answer other questions about the city and nature of its society.

Construction of Co Loa's rampart system

Most of the earthen materials used for Co Loa's rampart construction came directly from the ditches at their exterior faces. Visible within the rampart's stratigraphy were several construction sequences that employed varied building techniques, including simple piled earth along with forms of stamped earth reminiscent of *hang-tu* (stamped earth) methods of construction in Sinitic civilization. The layers of construction deposits can be grouped into three main chronological periods (Early, Middle, and Late Periods) based on major construction episodes, with several phases of building. The major construction events were identified through stratigraphic analysis, *in situ* artifacts, and a suite of radiocarbon and thermoluminescence determinations, with Phase 1 falling within the Early Period, Phases 2–4 corresponding to the Middle Period, and Phase 5 (refurbishment and amplification efforts) occurring within the Late Period. Phases 2–4 of the Middle Period are of most significance, making up the bulk of the original construction. For a number of reasons, the primary function of the ramparts appears to have been defense, although they may have served other functions as well (see Kim 2015) (see Figure 2.2).

Radiometric and stratigraphic data indicate that most of the rampart (Middle Period: Phases 2–4) was constructed without interruption, within an approximate range of 300 – 100 cal BCE. Above the Phase 4 sequence,

Figure 2.2 Excavation profile within the Middle Wall at Co Loa

construction methods and artifacts show that the upper layers of the rampart correspond to the Late Period (Phase 5) and were likely carried out by a different society or political entity as part of a refurbishment or amplification episode.

Construction of the ramparts began with a foundation of soil dug out from the nearby source areas, wherein clumps of soil were dug up, transported, and deposited to create a flat foundational surface. Initial layers of deposition consisted of topsoil from rice paddy fields, implying that intensified rice farming was occurring within the Co Loa area prior to the monumental constructions. Rampart construction (Phase 2) commenced sometime during the late fourth or early third century BCE. Most of the artifacts for this Middle Period, consisting mainly of ceramic roof fragments and stones, were recovered from within the Phase 4 sequence at approximately one m below the extant rampart surface. These roof tiles and stones were part of the royal or elite-level material remains of the Co Loa Culture, similar to materials found in excavations of an area within the Inner Wall and dating to the same period. Artifacts related to the Co Loa Culture, particularly the roof tiles, were found only within the expanse of the Co Loa site, standing in contrast with artifacts of the contemporaneous Dongson Culture that have been found at sites throughout northern Vietnam's Red

River Valley region in various contexts. Because of this key distinction, the Middle Period (c. 300 – 100 BCE) is considered the Co Loa Culture period, one associated with the Co Loa polity. The roof tiles were located along the entire length of all three enclosures, within the same stratigraphic layer. Surveys at collapsed areas of the ramparts revealed the presence of the roof tiles, suggesting consistency in chronology and construction efforts for the entire rampart system.

The chronology for rampart construction is noteworthy in two ways. Firstly, the evidence demonstrates that monumental constructions occurred well before Han imperial annexation of the region, implying that a local and indigenous society was responsible for construction. The bulk of the rampart system appears to have been deposited within a maximum window of two centuries, likely commencing at around 300 BCE. This tentative interpretation appears fairly consistent with descriptions offered in ancient Vietnamese chronicles. These chronicles stipulate that a single kingdom, namely the Au Lac Kingdom, was responsible for the founding of Co Loa and the construction of its ramparts at an ascribed date of 257 BCE (O'Harrow 1979; Taylor 2013). While these data do not provide definitive substantiation for the validity of such textual accounts and for the existence of the Au Lac Kingdom, they do provide additional support for the hypothesis of a major construction effort taking place before the Han Empire annexed the region. Secondly, the data provide a starting point to consider Co Loa's sociopolitical organization. For that effort, it is necessary to complement the chronological data with energetic information to furnish insights about how people, materials, and resources may have been organized.

Architectural energetic calculations

Researcher Charles Higham (1996, 122) estimates that approximately two million m^3 of materials were moved in the construction of Co Loa's rampart system. Elsewhere, Kim (2015) used known measurements of the ramparts to produce an independent approximation. The general dimensions for just the rampart constructions were calculated, using a combination of published data and surveys conducted at the site (Kim 2010; Nguyen 1970; Nguyen and Vu 2007). In sum, a conservative estimate for the amount of earthen material involved for the ramparts would be approximately 1,057,100 m^3 for all three enclosures (see Kim 2010 for details). The estimate, though, is conservative in that it does not include any material or labor requirements necessary for the construction of additional buildings and features that likely marked the overall cityscape. It should be noted, too, that these estimates do not account for centuries of decay and dereliction that may have reduced overall dimensions, nor do they consider additional architectural features, such as watchtowers, guardhouses, bastions, walkways, possible roofing, gates, stone or brick facings, waterway locks, among others, all of which would have increased the overall construction costs. Therefore,

significantly more than one million m^3 of material may have been involved in the original system. Ultimately, however, one million m^3 is a fair starting point for energetic calculations.

The next step is to determine the building process and activities along a *chaîne opératoire*, as well as an appropriate rate of construction for the ramparts. This would encompass extraction and procurement, transport and deposition, along with actual construction techniques. A substantial literature exists for historic and archaeological cases from different geographic and chronological settings that presents labor cost estimates for various constructions utilizing an assortment of digging and building techniques (Abrams and McCurdy, Chapter 1). Various studies shed light on variables to consider, including soil composition, appropriate number of hours in workdays, tools, and others. Through analysis of comparable proxy data, Kim (2015) determined an appropriate set of work rates in a tropical zone as a starting point for the Co Loa case.

For instance, Charles Erasmus (1965) proposes a rate of 2.6 m^3 per day for one person to dig earth. However, other factors such as transportation and types of materials can play a significant role in calculating labor costs (Arco and Abrams 2006, 911). Elsewhere, Mesopotamian written sources, specifically Old Babylonian texts concerning canal excavation, hold that a single worker could excavate 3 m^3 of soil in a day, although the workday was specified as ten hours (Burke 2008, 145). In a study of canal construction in the Moche Valley, Billman (2002, 376) estimates a rate of 1 m^3 per day for one person to excavate, which is based on the specific gravity of adobe clay soil. Because excavation rates vary considerably given different soil conditions, Billman (2002, 376) errs on the side of caution and uses a lower rate of 1 m^3 per person-day. With a similarly conservative approach for a Southeast Asian case, Chantaratiyakarn (1984) estimates that a person could move 2 m^3 of fill a day, with two other persons being necessary to move the material to the edge in studies of the moat excavations at the Ban Chiang Hian site in Thailand. This would then equate to three persons needed per day for every 2 m^3. Ultimately, as pointed out by Xie and colleagues (2015) in an innovative study, energetic studies related to earthwork construction ought to consider a range of variables, including choices in tools, soil types, attrition rates for digging implements, and others.

For Co Loa and its use of stamped earth, studies from China are helpful. Examining the Bronze Age settlement of Baodun in China's Chengdu Plain region, Flad and Chen (2013, 85–87) provide an insightful overview of labor estimates for the production of walls. They argue that laborers working with soil that was not particularly rocky could have moved as much as 3 m^3 per day in cases without *hang-tu* construction, and that 1 m^3/day would be a good estimate for *hang-tu* walls. Another very useful proxy case comes from China where an experimental study conducted at the Longshan Culture site of Wangchenggang in the Henan Province collected data using traditional tools and *hang-tu* construction methods (Rowan Flad, personal

communication, 2011). According to Flad, the results demonstrated that if tasks (which include digging, transport, and stamping) are appropriately proportioned, a single person could average 1.97 m^3 per day, although this estimate does not consider the depth of the borrow pit and difficulty of extracting materials from a pit. Hence, he advocates using a more conservative rate of 1 m^3 per person/day for construction of stamped earth walls.

With such comparable rates in mind, a conservative rate of one person required to excavate 1 m^3 of earth per day is reasonable as a starting point, although additional persons may have been required to move the materials to the edge and to the location of deposition, especially as the source ditch deepened. Moreover, it is plausible that more persons would have been required to work on the actual construction of the layers for the rampart, particularly for any sequences involving stamped earth, which can also involve the construction of elaborate wooden braces to be filled in by earthen materials. With these requirements, a safe, conservative estimate would be three to five persons per m^3 of material per day for the entire process starting from extraction to construction. To be sure, construction methods would have varied by construction episode, with some involving simple piled earth, while others involved more specialized techniques. Based on the aforementioned total volumetric estimate of 1,057,100 m^3 for the system of ramparts, using this range for work rates yields a total estimated range of 3,171,300 to 5,285,500 person-days to construct the rampart system.

Assuming that work could be conducted year-round with no interruptions and using a conservative rate of five persons per m^3, the task for one million m^3 of earthen materials, from extraction to construction, would require approximately 150 years, 15 years, or 1.5 years, respectively, for workforces of 100 people, 1,000 people, or 10,000 people (see Table 2.1). However, potential constraints, such as weather conditions, also need to be considered. Social and economic factors, such as beliefs about appropriate work intervals, labor related to agriculture, and fluctuations in the sizes of workforce also may have impacted work schedules. In accounting for such constraints, it may be prudent to consider a scenario involving partial work years, which would impact the estimates. Using an estimate of 175 days per work year, for instance, provides requirements of approximately 300 years, 30 years, or 3 years for workforces, respectively, of 100 people, 1,000 people, or 10,000 people (see Table 2.1).

Table 2.1 Labor requirements for construction of ramparts in years

Labor force	*Number of person-days required*	*Years required (working year-round)*	*Partial years required (working 175 days/year)*	*Partial years required (working 100 days/year)*
100	52,855	148	302	529
1,000	5,286	15	30	53
10,000	529	1.5	3	5.3

In the end, it is plausible that a workforce numbering in a range from 1,000 to 10,000 would have been able to complete much of the construction of the ramparts in 3 to 50 years. This estimate assumes a very conservative rate of five persons per m^3. Accepting a more aggressive rate, with more earth being moved and shaped into rampart architecture in a day, the time requirements would obviously drop. However, as stated earlier, these estimates do not account for additional architectural aspects and features of the fortifications, but it does convey the general cost requirements for the system. In any event, a total timeframe of no more than two to three generations would have been sufficient for completion for the majority of the rampart system.

These estimates seem reasonable when compared with those of monumental constructions in other studies. For comparative purposes, data from the earthworks at the North American Archaic site of Poverty Point in Louisiana can be instructive. The site consists of a 3 km^2 complex of nearly 765,000 m^3 of mounded earth in six nested, elliptical half-rings, two massive mounds, two conical mounds, and one flat-topped mound (Kidder et al. 2009, 1–2). Poverty Point's most prominent architectural feature is Mound A, which holds the distinction of being the largest human-built earthwork in what is now the United States at the time of its construction, and it remains one of the largest mounds built during the Archaic Period north of the Basin of Mexico. Similar to the Co Loa case, some researchers suspect the construction of certain earthworks could have taken place within a short time frame, as demonstrated by the work of Kidder and colleagues on Mound A (Kidder et al. 2009, 115–116). Based on chronometric and geoarchaeological data gathered from Mound A, with an estimated volume of 238,500 m^3 of earthen materials, Kidder and colleagues (2009, 77, 116) propose rapid completion as part of a single, continuous effort, perhaps within a matter of months. The researchers suggest that a minimum labor force of 1,000 to 3,000 individuals was simultaneously engaged in the construction of Mound A, indicating a significant population resident at Poverty Point, even if only for a brief period of time (Kidder et al. 2009, 137). With such estimates in mind, a major implication for Co Loa is that the ramparts could have easily been constructed within a single generation, if the right social conditions were present, along with availability of labor and material resources.

Another illuminating case study concerns the stamped earth city wall of the Zhengzhou site (c. 1600 – 1300 BCE) in China's Henan Province of the Erligang Culture, whose labor demands are discussed by Bagley (1999, 165). Zhengzhou's main feature is the *hang-tu* city wall, measuring nearly 7 km in circumference. This is somewhat similar to Co Loa's outer enclosure, which measures 8 km in circumference. According to Thorp (2006, 84–85), a hypothetical force of 10,000 laborers might have needed approximately eight years to construct the entire wall at Zhengzhou. These calculations reinforce the notion that a Co Loa Polity workforce numbering in

the few thousands could have constructed the basis of the rampart system within two to three generations, if not far less.

Implications for Co Loa's sociopolitical organization

As the other contributions of this volume amply illustrate, compiling architectural energetic data can help produce insights related to political authority and sociopolitical complexity by quantifying labor costs for the ancient construction of monuments, edifices, and features. Societies of various scales and kinds worldwide have engaged in monumental construction. Of course, there are anthropological and archaeological cases of smaller-scale, non-state societies producing monumental architecture, but these are typically public works built incrementally over long periods of time, and not necessarily through state-level control (Erasmus 1965, 278). With the Co Loa case, however, the rampart constructions are not only marked by a massive scale but are striking given the apparent rapidity of building processes.

The energetics data, when combined with other archaeological evidence, suggest that construction of Co Loa's rampart system corresponds to a highly complex and politically centralized society (see Kim 2015 for more). The extensive system appears connected in an overall design, likely serving to demonstrate the power and capabilities of the society. In addition, the construction signaled an intention that the rampart system would persist over time in serving various functions. Beyond deterrence and defense, the walls displayed the durability of power responsible for its undertaking. This element of persistence undoubtedly required ongoing investment of resources and labor for maintenance, extending the costs of construction indefinitely. This is an especially salient point when we consider the nature of the raw materials being utilized, namely soil and clay in an environment prone to monsoonal rains. The relatively rapid nature of construction, together with the requirements necessary for indefinite upkeep, combine to suggest: 1) centralized vision and implementation of a larger plan; 2) sustained control and direction of construction efforts and requisite resources; 3) availability of labor and personnel beyond construction, for indefinite maintenance; and 4) availability of a large-scale military force to man defensive positions. These characteristics therefore suggest a high degree of centralized control, possibly over voluntary, slave, or corvée labor. The case constitutes one of the earliest examples of both urbanism and archaic statehood for Southeast Asia, and its material record indicates local and indigenous trajectories of cultural change. In other words, the Co Loa polity emerged without direct imposition of "civilization" from the north.

Nevertheless, the archaeological evidence for the region clearly indicates contact and interaction between this area and various societies to the north during the second and first millennia BCE (see Allard 2014; Brindley 2015; Yao 2010, 2016). Indeed, Co Loa's material record indicates how knowledge of Sinitic forms of leadership and authority may have affected

local decisions and leadership strategies of elites (see Kim 2015). The most relevant material indicators consist of the use of roof tiles and stamped earth building methods. As discussed, portions of the Middle Wall exhibit techniques bearing some resemblance to the *hang-tu* method of stamped earth seen in parts of Neolithic and Metal Age China. Although use of stamped earth for construction projects is not unique to China, its presence at Co Loa suggests both interaction and emulation. Furthermore, Co Loa's roof tiles are stylistically comparable to Sinitic styles of roof tile design. In contemporaneous sites of present-day China, such tiles would have been reserved for elite or royal buildings. Their uses at Co Loa likely reflect emulation as part of local leadership strategies for consolidating or legitimizing political authority. As mentioned, the tiles are found nowhere else in Vietnam. This would further bolster the idea that Co Loa leaders appropriated ideological symbols of authority from the north and reconstituted them with local cultural and political meanings. This situation should not be surprising given Co Loa's geographic position on the southern frontier of Sinitic civilization, and this frontier context provides an interesting parallel for our consideration of the Korean Peninsula in the next section.

The Pungnap-toseong (風納土城) case of South Korea

Historical background and recent findings

According to a combination of archaeological and textual sources, the Baekje Kingdom was located in the southwestern portion of the Korean Peninsula from the first century BCE to the seventh century CE. Wiryeseong was the overall name of two early capitals of the kingdom, both believed to be located in the area of present-day Seoul and either to the north (Habuk Wiryeseong) or south (Hanam Wiryeseong) of the Han River. The remains of the Pungnap earthen rampart (also known as Pungnap-toseong) have been long viewed as a fortification feature associated with the Hanam Wiryeseong capital city. Archaeological studies over the last 50 years have considerably expanded our knowledge of this fortification feature of early Baekje, and recently scholars have officially recognized Pungnap-toseong as the northern castle "Buk-seong" of Hanam Wiryeseong (Seoul Baekje Museum 2015). The first excavation of Pungnap-toseong's ramparts occurred in 1964, and four surveys on different portions of the ramparts were carried out in 1997, 1999, 2011, and 2015. Fieldwork involving the inner villages and external facilities in Pungnap-toseong are ongoing (National Research Institute of Cultural Heritage [NRICH] 2014, 31).

The Baekje Kingdom stemmed from Baekje-guk, one of several Mahan Culture polities, located in the Han River basin, and eventually developed into a powerful state known as "Baekje". The seat of power alternated between three capitals, namely the Hanseong, Ungjin, and Sabi capital cities (see Table 2.2). The Baekje-guk polity purportedly emerged in competition

Table 2.2 Baekje capital cities and its rampart sites, stages of Baekje development

Phase	*Capital city*	*Rampart site*	*Present-day location*	*Date*	*References*
Baekje-guk	Pungnap moated settlement		Han River, Seoul	100 BCE–250 CE	Han 2013; Park 2009, 2012
Hanseong Baekje	Wiryeseong	Pungnap-toseong Mongchon-toseong	Han River, Seoul	250–475 CE	Han 2013; Park 2009, 2012
Ungjin Baekje	Ungjin	Gongsan-seong	Geum River, Gongju	475–538 CE	Samguk-sagi 三國史記 (1145)
Sabi Baekje	Sabi	Busosan-seong, Buyeo-naseong	Geum River, Buyeo	538–660 CE	Samguk-sagi 三國史記 (1145)

with neighboring Mahan polities and a commandery established by the Han Empire and developed into Hanseong Baekje polity between the first and third centuries. Subsequently, it expanded its forces to the south and succeeded in unifying the southwestern part of the peninsula by conquering southern Mahan societies in the mid-fourth century (369 CE). "Hanseong Baekje" is the term used to refer to this early Baekje Kingdom, which developed around the capital city known as "Pungnap-toseong." Hanseong Baekje also refers to the formation of Baekje's central style of cultural elements or central government. Until 475 CE, when Goguryeo invaded the Hanseong Baekje and the capital had to be moved to the south (the Ungjin capital city, Gongju), Pungnap-toseong functioned as the capital and stronghold of the Baekje polity. Seeking another chance to rebuild the state, in 538 CEBaekje moved the capital to a new city called "Sabi".

This section offers an analysis of the ramparts of Pungnap-toseong, located in the Han River basin in the southern part of present-day Seoul, South Korea (see Figure 2.3). Much of the settlement's outer rampart remains standing, measuring approximately 2,700 m in circumference (north: 300 m, south: 200 m, east: 1,500 m). Its original circumference is estimated at 3,500 m if we take into account the western wall (which is no longer extant). The roughly oval shape stretches along a north-south axis, enclosing an area of approximately 859,504 m^2 (or ~86 hectares). The ramparts were built up using earthen materials from the plains around the Han River, and in the eastern length of the rampart ("East Wall") there are remnants of what appear to be four gates. Most recently and over the course of two field seasons in 2011 and 2015, the Pungnap East Wall and Ditch Project was undertaken by an NRICH team to investigate the size and construction methods of the earthen rampart. The project excavated a portion of the East Wall rampart and determined that Pungnap-toseong was built upon the "Pungnap moated settlement" and that the ramparts were expanded from the preexisting structure known as the "triple ditches" (see Figure 2.3). This large-scale landscape modification was purportedly completed at around 250 CE, and no later than the early fourth century (Kwon 2012, 94). The excavated section of the rampart runs in a generally north-south direction and the scale of the surviving East Wall is 43 m in maximal width (bottom), 5.8 m wide (at the top), and 10.8 m in height.

An examination of the excavation sections demonstrates that there were four construction phases within three periods of time (Period 1 (Early): Phases 1–2; Period 2 (Middle): Phase 3; Period 3 (Late): Phase 4; see Table 2.3). Phases 1–2 belong to the primary event for building the main framework, and Phases 3 and 4 consist of extension or amplification episodes in a later period. Based on radiocarbon dating and optically stimulated luminescence (OSL) dating, the construction of Phases 1 and 2 occurred during the Early Period (roughly 250 – 370 CE). Phase 3 occurred in the Middle Period (the mid-late fourth century), and Phase 4 occurred in the Late Period (early

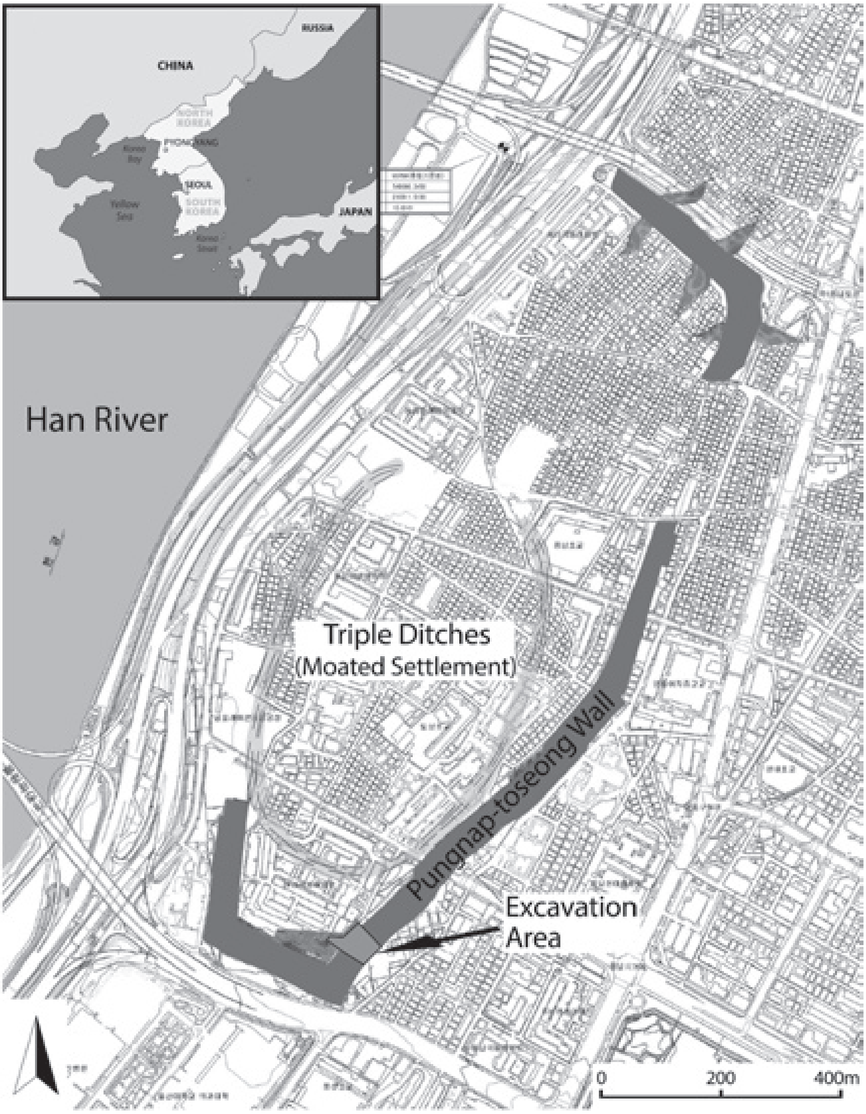

Figure 2.3 Location, excavation area

fourth century) (Lee et al. 2013; NRICH 2014; see Table 3.2). Admittedly, it is difficult to determine specifically how much time was required for the separate construction events. However, when taking into account the chronologies proposed by the excavation team, it seems at the very least that the main construction, consisting of Phases 1 and 2, took place within a window of approximately 50 years. Furthermore, the maintenance and expansion

Table 2.3 Rampart construction chronology (by Bayesian statistics), phases, and estimated dimensions (NRICH 2014, 219)

Phase	*Construction*	*Characteristics*	*Max. height*	*Width*	*Date*
1 (Early)	Foundation	A mix of leaves, gravel, and clay	4.3 m		c. 250–320 CE
2 (Early)	Embankment	Thin stamped earth Drainage facilities	10.8 m	5.8 m (top) 37.4 m (bottom)	c. 310–370 CE
3 (Middle)	Extension	Dumped clay Drainage facilities	11.8 m	7.1 m (top) 41.2 m (bottom)	c. 340–395 CE
4 (Late)	Extension Repair	Masonry Dumped clay Drainage facilities	13.3 m	7.6 m (top) 43 m (bottom)	c. 375–460 CE

efforts related to Phases 3 and 4 were seemingly carried out continuously every 50 years until 475 CE (see Figures 2.4 and 2.5).

For the construction methods of the earthen rampart, the excavation team proposed a multi-stage extension model with highly elaborate building techniques (NRICH 2014, 242). Their hypothesis is that the scale of the wall was augmented after the original main construction (Phase 1–2), with the two extension or amplification sequences (Phases 3 and 4).

In Phase 1, the foundation (*Jijeong*) was put into place to ensure the stability of the ground. The ground surface at that time was reformed by using techniques such as consolidation (壓密, 固結) and compaction and it was reinforced by adding an earthen mound with a maximum height of 0.9 m in the section (width 11 m) where a frame structure would be installed (see Figure 2.6a). Interestingly, within the foundation area was a layer of clay mixed with the remains of plants (approximately 0.5–1 cm in thickness) that likely aided in the strength of the foundation. This method of earthen construction is highly specific to the Baekje Culture.

In Phase 2, the ramparts (5.6 m in width) were built up above the foundation area, and this was the main wall. It consisted of a total of 148 layers. The builders used a stamped earth technique (called *panchuck* in Korean), which also resembles the *hang-tu* methods of ancient China. This method involves the deposition of alternating layers of different kinds of soil within wooden bracing, with layers being tamped down. The estimated scale of the wall in this stage is 37.4 m wide at the bottom, 5.8 m wide at the top, and 10.8 m in height (see Figure 2.6a).

Interestingly, many ceramic fragments were recovered within the Phase 2 layers. These artifacts appear to be imports from Han sites, and some

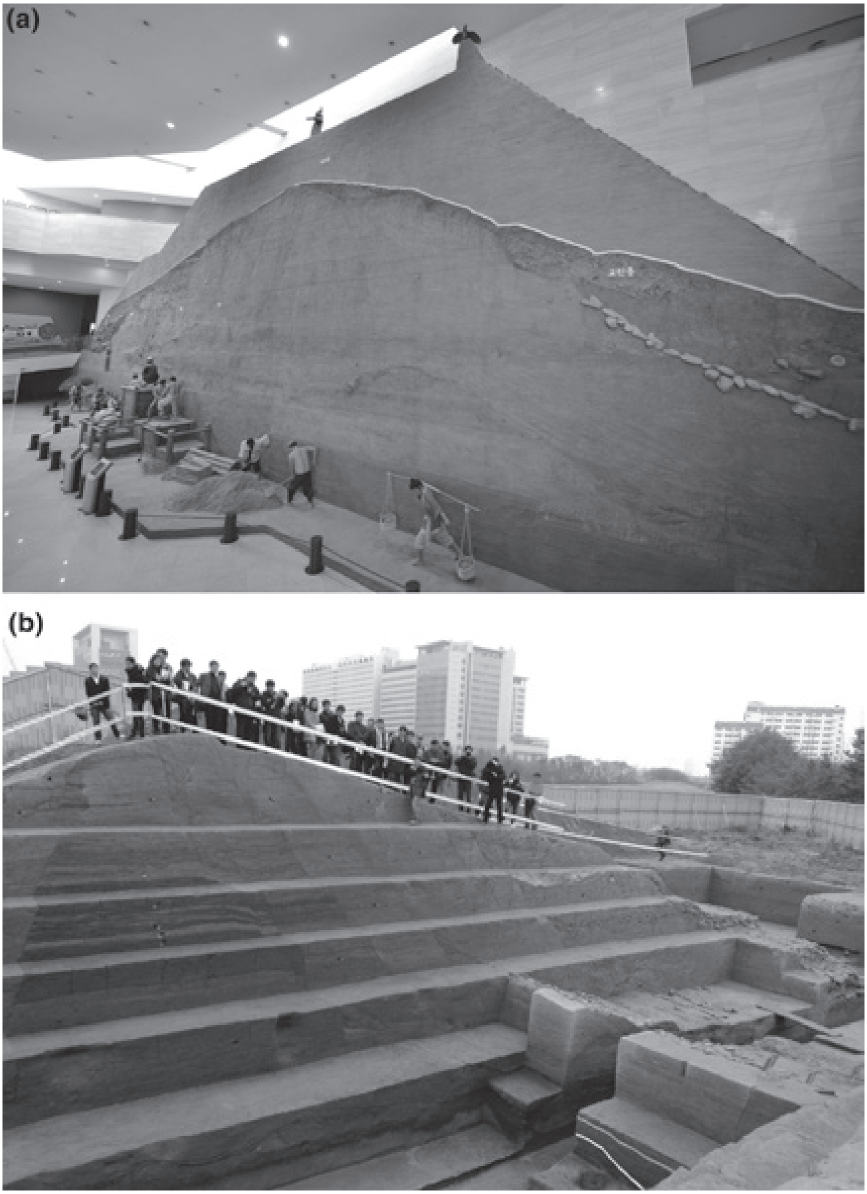

Figure 2.4 Photographs of the Pungnap Earthen Rampart from two views shown in (a) and (b). (Seoul Baekje Museum 2015)

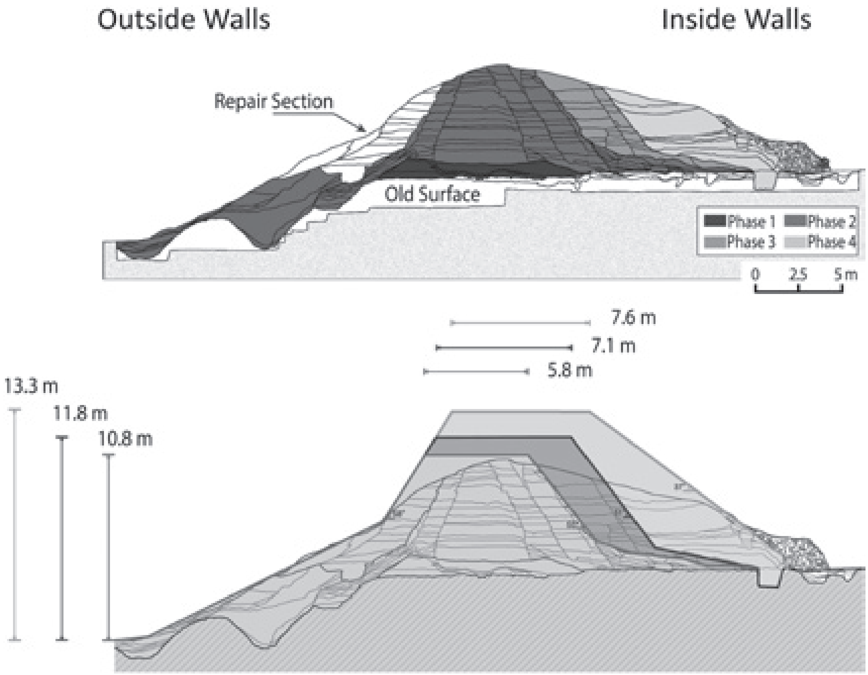

Figure 2.5 Construction phases and estimated dimensions of the Pungnap Earthen Rampart at excavation location (redrawing based on Figure 2 in Lee et al. 2013, 46 and Figure 110 in NRICH 2014, 246)

researchers suspect these materials may have been prestige items with distribution restricted to elite contexts (Lee et al. 2013, 51; Park 2012, 67–68). There are interesting parallels between this situation and that of Co Loa. Arguably, the presence of these artifacts at Pungnap-toseong, along with the stamped earth layers, also suggests the possibility of influence or emulation among local leaders. Perhaps even more interesting is the presence of roof tile fragments also scattered within the fill of Pungnap-toseong's ramparts. For this time period in the Baekje area, such roof tiles had only been found at Pungnap-toseong. As will be discussed later, this may reflect an analogous context of emulation as seen with the Co Loa polity.

With the first extension episode of Phase 3, the width and height of the wall were expanded and a new drainage channel (width 108 cm, depth 90 cm) was installed. The estimated scale of the wall in this stage is 41.2 m wide at the bottom, 7.1 m wide at the top, and 11.8 m in height (see Figure 2.6b and 2.6e). Phase 4 consisted of a second extension episode and the final construction effort of Pungnap-toseong before the eventual invasion by the Koguryeo polity in 475 CE. It involved a layer of dumped earth and clay blocks of various sizes with stone facings to reinforce the

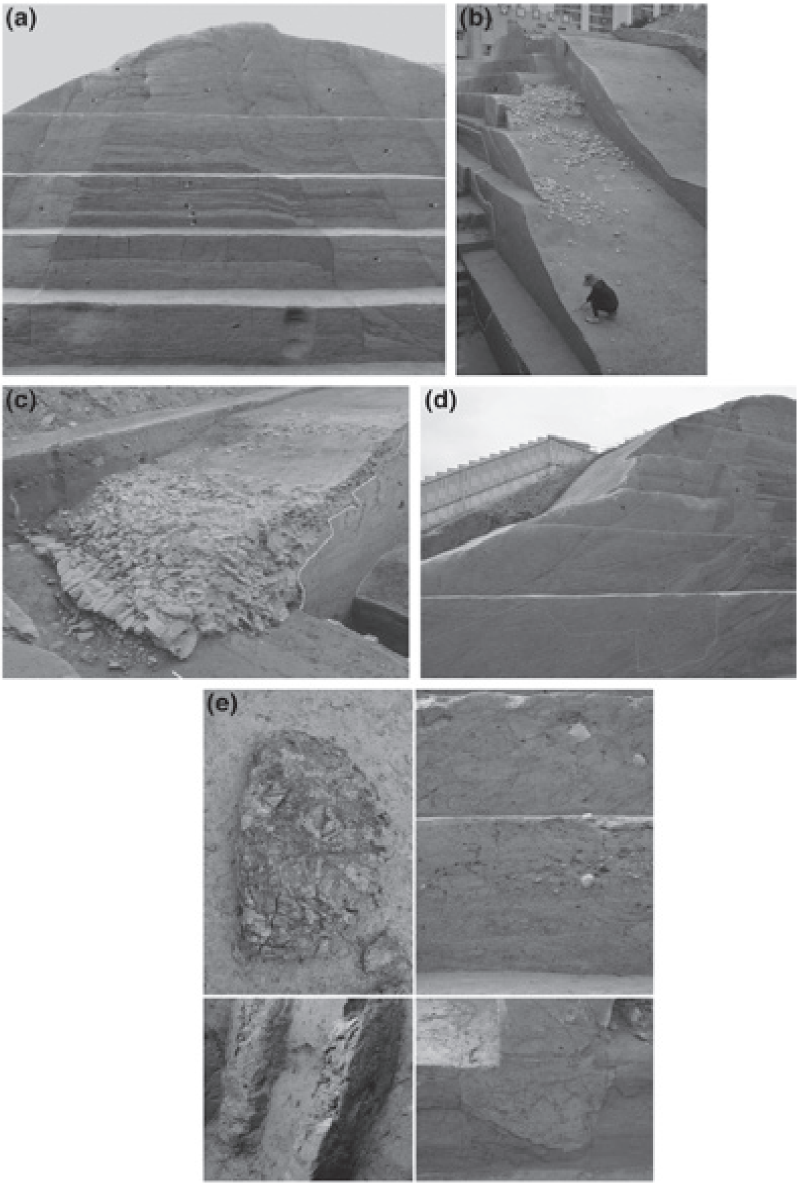

Figure 2.6 Location of the Pungnap Earthen Rampart and excavation area – a: thin stamped earth applied in the framework of the wall (Phase 2); b: stonework for reinforcing the first wall built in Phase 2; c: stonework for adhesion enhancement in the second extension sequence (Phase 4); d: external wall repair and reinforcement work; and e: building techniques seen in the process of the second extension sequence (Phase 4) – clay blocks (top row) and drainage channel that was installed in the first extension sequence (bottom row)

walls and prevent slippage and erosion. The estimated size of the wall in this stage is 43 m wide at the bottom, 7.6 m wide at the top, and 13.3 m in height (see Figure 2.6c–e).

Construction and labor requirements

The general dimensions offered here for Pungnap-toseong are based on the portions that are still standing and intact, and on the published reports regarding the recent excavation of the East Wall, provided by NRICH (2002, 2014). As mentioned, the circumference for the ramparts is approximately 3,500 m, and its cross-sectional area is 201.2 m^2. A conservative estimate for the total amount of earth moved to construct the ramparts would thus be approximately 704,200 m^3 (see Table 2.4). It must be noted that these estimates neither account for centuries of decay that may have reduced the overall dimensions nor factor in any additional architectural features (e.g. watchtowers, roofing, or other structures), all of which would certainly have increased the overall costs of construction. Nevertheless, the chronological and construction data from systematic excavations (see NRICH 2014) provide a working context for analysis. Furthermore, data from the excavation of the outer moat, carried out in 2015, made clear that the majority of the earth used to construct the original portions of the wall (Phases 1–2) would have come directly from the area outside its exterior face, thereby simultaneously creating the moat (see Table 2.5).

Although an architectural energetic study for the Pungnap-toseong site has never been completed, the excavation team (NRICH 2014, 247) has

Table 2.4 General dimensions of the Pungnap-toseong ramparts (NRICH 2014)

Circumference (m)	*Cross-sectional area (m^2)*	*Estimated volume (m^3)*
3,500	201.2	704,200

Using the total of 704,200 m^3 as the baseline, the next step was to settle on appropriate rates of construction labor (see Table 3.5)

Table 2.5 Rates of labor and time associated with monumental architecture

Architectural feature	*Location*	*Volume (m^3)*	*Persons*	*Days*	*References*
Maya structure	Copan, Honduras	2.6	1	1	Erasmus 1965
Canal	Moche Valley, Peru	1	1	1	Billman 2002, 376
Moat	Ban Chiang Hian site, Thailand	2	3	1	Chantaratiyakam 1984
Rampart	Co Loa site, Vietnam	1	5	1	Kim 2013
Rampart	China (Tang Dynasty)	0.51	1	1	Tongdian 通典 (801)

speculated that the rampart construction would have required at least 1,380,000 persons to complete in a given one-year time frame, though the researchers do not offer other specific information. This calculation needs to be juxtaposed against systematically collected material data related to both construction methods and local social conditions of early Baekje society.

Although separated by space and time, there are rough similarities between the Pungnap-toseong and Co Loa cases. As described above, both are located on the fringes of expanding Sinitic civilization, and both settlements had elite residents that likely made use of emulative strategies in their own efforts to centralize political authority. Based on these characteristics, plus the use of variations of stamped earth methods for rampart construction as well as restricted roofing techniques, we believe it practical to use similar reasoning when considering rates of labor, especially since an architectural energetic appraisal for Pungnap-toseong ramparts has never been attempted. Consequently, we proceed by adopting rates of construction presented in the preceding section for the Co Loa case.

Within Phases 1–2 of the rampart, we propose that the framework made by the *panchuck* (stamped earth) technique would have required at least two to three persons per m^3 per day. We argue that a reliable rate is six persons per m^3 of material per day for the entire process starting from extraction to construction. We arrive at this number based on a combination of proxy estimates taken from the Co Loa case, as well as insights derived from the Tongdian textual descriptions.

Additionally, it is important to consider some of the cultural factors related to Baekje society. According to the historical text known as *Samguk-sagi* 三國史記 (1145), Baekje, as an agricultural society, forbade large-scale mobilization of labor during farming seasons (possibly from April through June and October; see NRICH 2014, 225). This historical record suggests that the Baekje society utilized a corvée labor system as taxation for contributions to civil work projects. In addition, according to the *Annals of the Joseon Dynasty* 朝鮮王朝實錄 (1413–1865), the duration of labor mobilization was limited to 20 days in ancient Korea, at least during the later Joseon period. Considering these ancient operating principles related to labor, we propose using a window of 180 days per year that can be safely dedicated to construction projects such as the rampart system (or some 20 days in a month out of nine months in a year).

Based on the earlier estimate of 704,200 m^3 for the total volume of the ramparts (Phases 1–4), and using the rate of six persons per m^3 per day, we arrive at a total figure of 4,225,200 person-days to construct the ramparts (see Table 2.6). Using an estimate of 180 days per work year requirements are modeled at 240 years, 24 years, and 2.4 years for workforces, respectively, of 100 people, 1,000 people, and 10,000 people (see Table 2.7). When taking into account the published chronological data, the whole process of construction for the ramparts, including the later extension and amplification phases, likely required at least 100 years (Phases 1–2: 50 years, Phases 3, 4:

Table 2.6 Labor requirements for construction of ramparts in person-days

Labor force	*Number of person-days required (1 person per m³)*	*Number of person-days required (3 persons per m³)*	*Number of person-days required (6 persons per m³)*
1	845,040	2,535,120	4,225,200
100	8,450	25,351	42,252
1,000	845	2,535	4,225
10,000	85	254	423

Calculations are based on different rates of construction (1-, 3-, and 6-person teams per cubic meter)

Table 2.7 Labor requirements for construction of ramparts in years

Labor force	*Number of person-days required*	*Years required (working 180 days/year)*
100	42,252	238
1,000	4,225	24
10,000	423	2.4

respectively, about 25 years each). It is very likely that a labor force ranging from 1,000 to 2,000 would have been able to complete the ramparts in a time frame of 25 to 50 years. Interestingly, ancient textual records indicate that 3,000 adult men living in the local area were mobilized in the construction for two fortresses in 486 CE, although this was for a different polity, namely the Silla (National Institute of Korean History 1995, 209, referred to in the *Samguk-sagi* 三國史記 1145). Nonetheless, the account provides a clue that our proposed estimates are reasonable.

Population levels and demographic changes

To complement the architectural energetics estimates, we now turn to settlement data from approximately 250 CE (prior to Phase 1) to 475 CE (the end of the Hanseong Baekje period) in order to estimate population and potential labor levels. Would a potential labor pool have been present to perform such large-scale civil engineering works, and what changes over time are discernible? As discussed earlier, assuming that the first construction (Phases 1–2) took either 25 or 50 years, we estimate a requisite labor force of 1,000–2,000. According to the historical text *Samguk-yusa* 三國遺事 (1281), the total number of households for Baekje at its peak was 152,300. Based on this record, there has been a tendency to believe that the total population during the period of King Geunchogo (346–375 CE) was approximately 700,000 to 800,000 (see Kim 1997). However, it would be difficult to unconditionally accept this estimate simply based on textual mentions, especially since the timing for the peak numbers is unclear.

Moreover, as mentioned above, the Hanseong Baekje society experienced frequent warfare with neighboring polities, some of which resulted in the expansion of Baekje's territory and cultural influence. Such outbreaks of conflict, detailed in various ancient chronicles, likely contributed to dramatic demographic changes throughout the region as well as within Baekje's sociopolitical organizations. Through the course of the third and fourth centuries, the Baekje polity expanded its territorial reach southward through military conquest, and this likely resulted in considerable social changes directly impacting local and regional demographics. Such textual descriptions, and their implications for population levels, require complementary material data.

Gathering such data involves an overview of the total number of Baejke residential buildings that have been investigated. This would provide data for calculating a baseline population estimate. Using insights from ancient texts, researchers suggest that a labor force can be inferred through the number of households, with estimates including one worker per household (National Institute of Korean History 1995, 205–210, referred to in the *Samguk-sagi* 三國史記 1145). Using this assumption as a starting point, Table 2.8 provides an estimate based on the number of households that have been identified. Residential data come from Korean excavation reports and previous studies (Heo 2011; Kim 2017; Park 2012; Park 2014; Song 2012; Yun 2014). Of significance are the considerable changes in household totals over time. Before the fourth century, the potential labor force was approximately 741, but that number grew to approximately 7,257 after the fourth century. Of course, these crude figures merely provide a tentative estimate to help generate discussion, but they do illustrate the possibility that social change, resulting from warfare and territorial expansion, could have considerably altered local demographics and potential labor pools.

We believe that the archaeological data support the hypothesis that Phases 1–2 of construction were carried out over the course of 50 years, concluding in the mid-fourth century. We also argue that this construction project was related to a series of territorial expansion events into neighboring Mahan territory, which led to a growing overall population for Baekje.

Table 2.8 Changes in labor force in the fourth century

	Before the fourth century (Han River basin and the central region including part of the Gyeong-gi province)	*After the fourth century (Expanded territory into southern regions, including the Jeolla province)*
Min. labor force estimate* (based on number of households)	741	7,257

*Assumes one laborer per household

It is within that pivotal time period that Baekje political leaders would have had sufficient labor resources to sustain Pungnap-toseong's monumental construction. Additionally, there is other evidence corroborating the military expansion of Baekje, specifically in the form of arson and destruction of villages in the archaeological record, which appears to increase in the Han River basin during the third-fourth centuries (Park 2012, 103). Warfare played a crucial role in population movement and likely contributed to subsequent social reorganizations within Baekje society. Indeed, some of the Baekje-style houses and artifacts begin to appear further afield, in portions of Mahan territory (e.g. the southern Gyeonggi province), mixing in with locally indigenous Mahan cultural materials. It is also possible that people living in the neighboring Mahan Culture areas voluntarily adopted or imitated Baekje lifeways, styles, and cultural practices, as exhibited by the presence of a hexagonal type house and the use of steam pots and heating practices (Song 2012, 58). The period is thus marked by significant cultural changes within the wider region, suggesting major interactions.

Sociopolitical leadership and construction of Pungnap-toseong

There were distinct forms of labor organization and energy expenditure that we propose would have corresponded with distinct styles of political leadership. For instance, the first construction of Pungnap-toseong's ramparts was carried out over some 50 years. Later, when Baekje had expanded in terms of controlled territory and population, its leadership would have been able to mobilize greater amounts of labor. According to ancient chronicles, the Baekje society operated a corvée labor system in addition to obligatory military service, reinforcing the idea that rulers officially managed workforces. If the purpose of building such monumental architecture was simply a practical one, such as building a palace or a fortress, the rulers could have shortened the construction period by mobilizing more people. However, we propose that the earthworks also functioned in a strategically symbolic way. As an expression of power, the construction of the ramparts signifies a distinctive leadership tactic. Participation in the project, regardless of role, may have also helped to promote notions of community and shared identity.

Hence, the city's monumental architecture is not merely an indicator that Baekje was a state, as suggested by Korean researchers (e.g. Park 2001, 2012; Shin 2017). Rather, such architecture and associated construction projects attest to political stability, enduring institutions, and power. In addition to serving as fortifications for defense and deterrence, the ramparts constitute large-scale, community-building efforts. This was especially the case after the military expansions during the third and fourth centuries. With the incorporation of new territories and populations, Baekje rulers likely needed to enact major sociopolitical reforms to reconfigure intra- and

inter-regional relationships. In other words, leaders needed to successfully recombine or integrate diverse groupings of people in new ways to create and maintain social stability.

With regards to social reorganization, many case studies across the world demonstrate how leaders employ ruling strategies with contrasting approaches of differentiation and integration. According to Eisenstadt (1964, 376), "differentiation" refers to the process through which social groups become dissociated from one another so that specific activities, roles, identities, and symbols become attached to them. This phenomenon can be witnessed in the changing patterns of settlements that interact as part of a network, as well as in the morphology of residence groups within settlements. On the other hand, "integration" denotes the political process in which differentiated social groups come to exist within an institutionalized framework of social relations. This can be revealed through symbols of incorporation, such as ritual spaces, temples, palaces, and monuments for people who are specialized precisely in the ideologies that legitimize the order of stratification of differentiated groups and individuals (Yoffee 2004, 32–33). It is plausible that Baekje's rulers would have engaged in mixed leadership strategies during expansion episodes.

In that sense, Pungnap-toseong's rampart construction could reflect a varied political strategy utilizing both differentiation and integration. It is clear that the first rampart project (Phases 1–2) occurred after warfare against Mahan polities (288–297 CE, as suggested by Kang 1997; see also Kwon 2015, 195–196), which resulted in officially differentiated statuses of the ruling classes. Textual sources indicate a legitimization of new forms of social orders and relations centered at the capital. Completion of the rampart system may have led to new cultural styles in pottery and housing to reflect newly emergent social units and relations among elite classes. These styles were marked by the hexagonal house type and pottery of the Hanseong Baekje Culture, which were located in and around Pungnap-toseong, the epicenter of Baekje Culture, within a radius 9–18 km (see Song 2010, 107).

Postwar administration of newly acquired and integrated territory likely required that rulers establish a new order of social relations or new rules to strengthen central authority over local areas, even if elements of local political decision making and autonomy were left intact to varying degrees. Additionally, while masking any political attempts to deconstruct such local power and autonomy, it would be necessary to devise sociopolitical mechanisms to build region-wide commonality for the new social order. Within this perspective, the Hanseong Baekje style, which emerged at around the same time as the completion of Pungnap-toseong, seems to have played a crucial role in setting physical, ideological, or symbolic distinctions between central and peripheral regions within Baekje society. Consequently, we propose that the construction of Pungnap-toseong, as part of a differentiation

strategy for social reorganization, ultimately contributed to the legitimacy of new forms of social order and political authority.

At the same time, such large-scale civil engineering efforts would have also served as a tool for integration. This would have been accomplished through the transformation of available symbolic and ceremonial resources of the differentiated groups into a new social collective. The process of building ramparts, which was an important official ritual for the Baekje state, may have itself been an important means of displaying leadership and solidarity. Rituals organized as collective or corporate action represent a particularly effective context for the use of persuasive power (Mills 2000, 8; see also Burns and Laughlin 1979). Joint participation in impressive and large-scale civil engineering projects could have conferred upon newly incorporated communities a sense of membership and a common identity. Furthermore, ritual systems involved in monumental constructions can also have a central role in promoting community solidarity by emphasizing cyclical, repetitive obligations to the community as a whole (Wills 2000, 33). Thus, Pungnap-toseong may have played a vital role as an integrative focus for different social members forced into alliances through the threat of force and warfare.

Regionally, the material evidence shows that the Hanseong Baekje style, regarded as an indicator of integration, rapidly spread into settlements of common groups in the subregions, and not just in elite settings. In many contexts, this Hanseong Baekje style appeared in mixed forms with indigenous Mahan material culture after the fourth century, coinciding with rampart construction at Pungnap-toseong (see Han 2005, 2009; Park 2006, 2009; Song 2010, 2012). Song (2012, 58) suggests that local people living far afield from the center of Baekje, especially in the southern part of the Gyeonggi province, were active in their acceptance of membership in the new social order. As highlighted earlier, construction of Pungnap-toseong's ramparts required a considerable amount of labor over the course of 50 years, and most of the workers were likely mobilized from southern regions that originally belonged to Mahan polities (see also Kwon 2012, 94). Baekje's rulers seem to have employed a dual strategy of "differentiation and integration," as embodied in the final construction of Pungnap-toseong's ramparts. The Baekje case demonstrates the need for social reorganization at around 400 CEto promote new forms of regional stability. This is supported by other material data, such as the results of spatial analyses on the expansion of Baekje and settlement reorganization (Park 2017; see also Yun 2014), which show that region-wide population concentrations and settlement distribution patterns before and after the fourth century are dramatically different. Park (2017, 93–94) argues that the varied patterns stem from different strategies employed by the Baekje polity in its diverse interactions with peripheral communities. Taken at face value, Park's conclusions imply that settlement reorganizations occurred simultaneously in almost all local areas within Pungnap-toseong's wider hinterland.

Concluding remarks

Inspired by pioneering studies, we have presented models for understanding two specific cases in Southeast and Northeast Asia. Although much more work remains to be done to refine and improve the baseline estimates provided in this chapter, it is our hope that the insights offered through considerations of the Co Loa and Pungnap-toseong cases can help, in turn, to shape future studies of these sites along with others in the wider region. We also hope that our research will contribute to ongoing studies of sociopolitical complexity as exhibited through monumental architecture and large-scale modifications to environments and landscapes.

The two cases offered in this chapter also provide a glimpse into processes of state formation within their respective areas and are particularly salient for comparative research as they were located along the frontiers of especially large-scale and predatory imperial polities of Sinitic civilization (e.g. Qin and Han). For the Red River Valley of Vietnam, the Co Loa case shows how local strategies of leadership and political centralization can become intertwined with material symbols of authority, even if they come from exotic and foreign sources. The monumental scale of earthworks within a city, combined with specific methods of construction (e.g. stamped earth) and architectural styles (ceramic roofing), speak to emulative practices designed to impress and to legitimize. The same can be said for the Pungnap-toseong case, where we see analogous cultural trends, leadership styles, and impacts of Sinitic civilization.

Both cases also illustrate how facets of imperialism and warfare can play pivotal roles in region-wide cultural changes. The cases highlight the ways in which large-scale construction projects and the organization of labor are intimately related to leadership strategies during times of major cultural flux. The marshaling of labor was not simply for the production of artificial landscapes and the practical benefits they furnished – such projects were also designed to symbolize power, control people, and to promote feelings of common identity. For Pungnap-toseong, in particular, there was a need to promote social stability in the wake of massive social reordering owing to violent territorial expansion. As noted by Yoffee (2004, 42), many ancient states emerged as part of the process in which differentiated and stratified social groups were recombined under new kinds of centralized leadership. Any chaos fomented by military expansions and warfare required the use of leadership tactics to help reestablish social stability within the region and to establish new social configurations. Ultimately, communal efforts requiring collaboration on significantly large scales can illustrate the capacities for people to cooperate. They also illuminate how opportunities can arise, within such collaborative efforts, for certain segments of such social groupings to promote their interests and further their political agendas. The use of architectural energetics allows researchers to systematically approach and appraise the tangible outcomes and remains of such collaborations.

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3 Pharaonic power and architectural labor investment at the Karnak Temple Complex, Egypt

Megan Drennan and Michael J. Kolb

Introduction

Broadly speaking, power is the variable ability to control social, economic, and ideological resources to achieve political goals. Manifest to the construction and upkeep of monumental works is tactical power and structural power (Conlee and Ogburn 2005; David 2004, 69; Henderson 2013; Wolf 1990, 586; Shackel 2001): respectively the ability to control how social discourse is negotiated, and the oversight of labor flow. Both are closely intertwined, and the creation or remodeling of a monument represents corporeal evidence of shifts in the balance of power, when labor is invested to redefine ideological discourse and social hierarchy (see Kolb 1991, 1994; Trigger 1990, 125). Thus, the energy invested in monumental works is reflective of the degree of cooperative popular effort involved in construction and use, and the degree to which elites and commoners are bound together by a common ideology of rulership.

We argue this is the case in ancient Egypt, where scholars have long correlated monumental works with social power. Egyptian rulers themselves appeared to link the two as well, as they competed with one another through a legacy of monuments. For example, those at the highest standing of the social and political hierarchy commissioned the building of the Karnak Complex, through construction phases that reveal political nuances between ruling dynasties. Though ancient Egyptians did not use the term we translate as "pharaoh" until the Nineteenth Dynasty of the New Kingdom, this chapter uses the term "pharaoh" for rulers of a united Egypt prior to the Nineteenth Dynasty, as it is a term closely tied with the prestige of reigning in ancient Egypt. For the same reasons, the phrase "pharaonic power" is meant to capture the authority (or lack thereof) of ancient Egyptian rulers.

The purpose of this research is to examine the time, energy, and material that individual pharaohs invested in the Karnak Temple Complex over the course of 2,000 years, from the rule of Senusret I in the Middle

Kingdom through Roman occupation. Our primary objective is to compare the relative efforts of each leader who built at Karnak to reveal the relative social power of each pharaoh. This was made possible by the Digital Karnak Project, designed and implemented at the University of California at Los Angeles (UCLA). Under the direction of Dr. Diane Favro (director of the Experimental Technologies Center) and Dr. Willeke Wendrich (editor-in-chief of the UCLA Encyclopedia of Egyptology), the Karnak precinct of Amun was mapped in three dimensions to provide a digital learning experience about the site and its architectural marvels. Our research employs these three-dimensional data to calculate labor investment costs over time.

We begin this chapter by first delving into the background of the architecture and labor of ancient Egypt, as well as Karnak's place within this historical context. Then, we outline our methodological model of labor mobilization, employing a volume-based measure of labor (cubic meters) rather than detailed energetic measurement for each building episode. We continue by examining three specific facets of pharaonic rulership: time, warfare, and administrative centralization. We conclude by providing a better understanding of the power and authority among Egyptian pharaohs as represented by the monumental architecture they left behind.

Background on Karnak

The Karnak Complex is located north of the ancient city of Thebes and the modern-day city of Luxor on the Nile River (see Figure 3.1). It is composed of three precincts dedicated to the gods Mut, Montu, and Amun (see Figure 3.2). Our work focuses on the largest of the three, the Precinct of Amun, and draws from a number of in-depth architectural and social analyses (Barrie 1996; Blyth 2006; Monderson 2007; Nims 1971; Schwaller de Lubicz 1999) as well as the Digital Karnak Project (Sullivan 2010; Sullivan and Snyder 2017). The significance of Karnak in the framework of Egypt cannot be overstated. Evidenced by the attention to building at the site over a great span of Egyptian history, Karnak had strong political and religious importance. There was a close relationship between the two forces of religion and leadership. As Blyth (2006, 2) wrote, "The temple in ancient Egypt was a place of power….Behind the high walls, daily rituals took place to maintain the well-being of Egypt and the equilibrium and harmony of the universe." To adorn Karnak was to better Egypt itself, and in turn, strengthen the pharaoh. The site was so meaningful that additions were added to the complex even during periods when the ancient capital was not at nearby Thebes. Leaders who were not native to Egypt chose to add to its history as well.

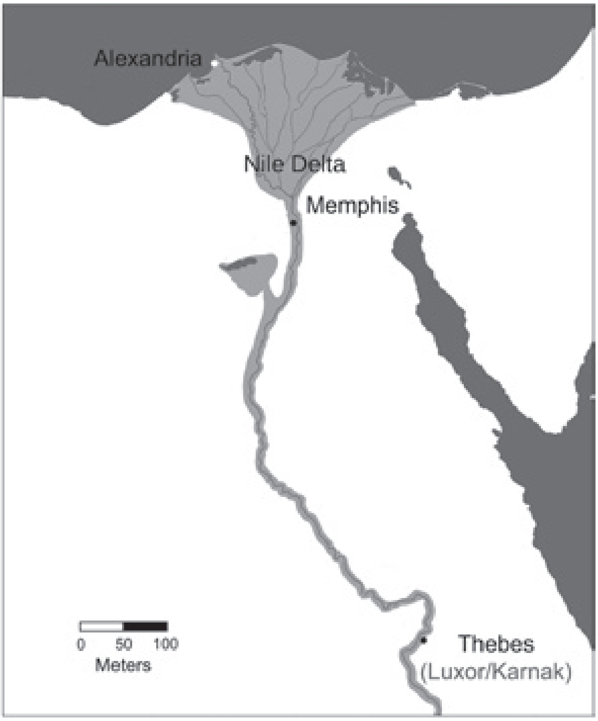

Figure 3.1 The Nile River with the three most important capitals of ancient Egypt. Thebes is the location of the Karnak Temple Complex

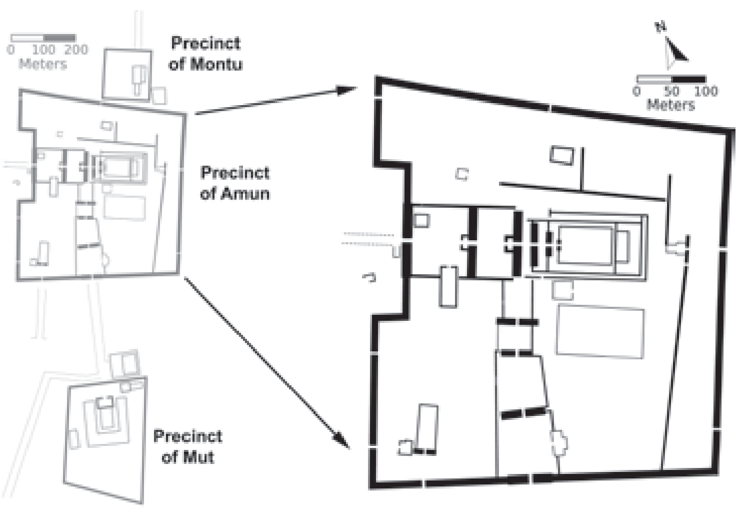

Figure 3.2 The Karnak Temple Complex, and the precinct of Amun (after Blyth 2006, 2 and Verner 2013, 177)

History of ancient Egyptian architecture

Much has been written regarding Egyptian monuments and through these works we have learned a great deal about the history and methodology of building in the region. The first true architecture in Egypt dates to 5000–4000 BCE and consisted of domed shelters made of wooden posts and reed mats erected over a sunken mud floor. Wattle and daub and mudbrick followed as construction materials, all easily sourced in the floodplains of the Nile (Badawy 1966, 11; Wright 2000, 51).

An important theme for Egyptian architecture, and Egyptian life in general, was religious ritual. Religion dominated all aspects of the ancient Egyptian life cycle. Badawy (1966, 7) described it as the "strongest stimulus of life." It is therefore unsurprising that the more durable mudbrick constructions were often funerary in nature. Continuing with tradition, once stone became the favored building material around 2500 BCE, it dominated religious monumental projects. Stone was more durable and costly but since longevity was valued in Egyptian beliefs, these characteristics made stone the ideal building material, as the "materials of eternity" (Badawy 1966, 35; Wright 2009, 56–57). In the span of a century, carved stone blocks, which were originally a small brick-like size, became as large as possible in a style known as "pharaonic masonry" (Clarke and Engelbach 1990; Wright 2009, 57).

The effort devoted to elaborate pharaonic funerary and religious construction is not surprising, as the duties of the pharaoh were intimately tied with religion. Although previous rulers had impressive tombs, such as mudbrick mastabas, the construction of a pyramid or temple complex was a preeminent symbol of political and religious authority. Equally impressive is the fact that pharaonic stone construction lasted almost unchanged until the time of the Romans, nearly 3,000 years after the first significant stone undertaking, namely Djoser's pyramid in 2778 BCE (Badawy 1966, 8; Wright 2000, 54). Nevertheless, there were fluctuations in the quality of material and engineering as the political state itself went through periods of challenge and prosperity.

How Egyptian monumental structures were built

It is relevant to keep in mind the state of technology and labor at this time. These Egyptians of course did not have the benefit of modern building technology, yet they efficiently built structures of impressive size and craftsmanship. Egyptians did not invent complex tools to carry out these ventures; they relied upon "intensive and careful use of the simple instruments and devices they had, such as sleds, barges, ramps, and ropes" and gradually improved upon their knowledge (White 2003, 9). This applied for all aspects of the construction process: quarrying, transportation, and assembly. This also applied for every construction detail. For example,

exterior walls were often built with a slight inward vertical slant, giving the illusion of greater height and grandness (Wright 2009, 150). However, many aspects of ancient Egyptian construction, especially assembly, remain poorly understood.

Labor in ancient Egypt

Recruiting laborers to work consistently and quickly was not always an easy task in ancient Egypt (Kadish 1996). There was a complex hierarchy in place at construction projects, organized to delegate tasks and command. Research suggests that builders in ancient Egypt were in fact compensated skilled laborers. The quarrying and transportation of stone was usually tasked to unskilled workers, frequently farmers who were relatively unoccupied for much of the year (White 2003, 10), and may have also included recruited foreigners or prisoners (Eyre 1987, 188).

Two sources help illuminate the work life of laborers. One source is the schedules for workmen from the village Deir el Medina, employed during the New Kingdom at the Valley of the Kings across the Nile from Karnak. The workweek was eight days of labor followed by two days of rest. Laborers were not required to work on weekends or on major holidays. Payment for the common laborer consisted of a monthly grain ration, while specialized roles received additional food (Eyre 1987). The second source, the Reisner papyri, offers insight into the work life of laborers during the Middle Kingdom (Kadish 1996). This set of papyri documents the "logistics of labor" and represents record-keeping of the time. It appears that absenteeism was incredibly common, with few workers reporting to work every day for the entirety of a project. Repeated shirking was punished; nevertheless, it is improbable that the physical coercion and threats of violence were the motive behind corvée labor (Kadish 1996, 446). Nor was unrelenting devotion to the pharaoh or to the gods a likely reason. Much like today, the institutionalized workday and the documenting of time and effort may have been the impetus. Laborers were paid for the time they devoted to the project rather than for a completed task (Kadish 1996, 444). This upholds the idea that monumental building was more dependent on political power, the ability to control and organize, than on economic or ideological influence.

Architectural history of Karnak

For the purposes of our study, the chronology of Karnak "begins" in the Middle Kingdom, when Senusret I of the Twelfth Dynasty built the first significant structures to grace the area: the White Chapel and Middle Kingdom Court. Yet, this tract of land had almost certainly been a sacred place prior to Senusret I's enterprise. Montu, a local deity worshipped at Thebes, had a temple in the area that may have dated to the Old Kingdom. As for Amun, the first strong evidence for a temple or shrine in his name dates to

the Eleventh Dynasty, around 100 years prior to Senusret I. Some scholars argue that, based on a cache of artifacts and a king list at the site, the Amun temple began much earlier than the Eleventh Dynasty (Blyth 2006, 8; Sullivan 2010, 2).

Nevertheless, Senusret I inaugurated a tradition of monumental building at Karnak during the Middle Kingdom (c. 2055–1650 BCE). Following his lead, pharaohs continued to add to the assemblage of temples, pylons, courts, and chapels that make up the complex. The rulers who contributed are listed in Table 3.1, along with the dynasty and period to which they belong. The Second Intermediate Period (c. 1650–1550 BCE) was characterized by a divided Egypt; the Delta was controlled by the foreign Hyksos while Upper Egypt was dominated by Theban rulers (Bard 2007). No significant building projects took place at Karnak during this period.

The rise of the Eighteenth Dynasty brought Egypt out of disunity and started the New Kingdom (c. 1550–1069 BCE). It was the most opulent building period of the Karnak Complex during a time of military accomplishments, expanding territory, strong foreign trade, and the reestablishment of the Egyptian kingship (Bard 2007). The temple complex in turn received a large royal income (Badawy 1966, 9; Bard 2007, 216). Thutmose II created the "festival court" which enclosed existing temples and established the crossing of the north-south and east-west processional routes (Blyth 2006, 47; Sullivan 2010, 6; UCLA 2008). Hatshepsut, hoping to leave her mark, began numerous projects, including the Red Chapel. The Red Chapel housed the sacred bark of Amun, which was central to religious festival processions, and was built from highly valued red quartzite (Blyth 2006; Sullivan 2010; UCLA 2008). Thutmose III left behind Akhmenu, an elaborately decorated temple complex of its own, as well as Contra Temple, a rare public space (Bard 2007; Blyth 2006; Sullivan 2010, 8; UCLA 2008). These are only a few examples of Thutmose III's rigorous building campaign. Karnak survived a brief interlude when Akhenaten attempted to restructure the traditional religion and reestablish the eroding status of royal religious authority. This disconnect, and the increasing influence of the Theban Priesthood of Amun, may have further distanced the kingship from religious authority since the king no longer served as an intermediary between the commoners and the gods (Bard 2007). Nevertheless, some significant building projects took place following Akhenaten, such as the imposing Hypostyle Hall started by Sety I and finished by his son Ramesses II during the Nineteenth Dynasty (Bard 2007; Sullivan 2010; UCLA 2008).

By the end of the Twentieth Dynasty, the Priesthood of Amun had become a formidable power of its own and controlled most of the Egyptian economy (Shaw 2000; Bard 2007). Despite this influence, there are no building episodes credited to the priesthood. Although the high priest under Ramesses IX took it upon himself to approve several inscriptions praising his excellent work to the pharaoh and Amun, the texts also acknowledge the buildings are in the name of Ramesses IX (Blyth 2006, 181). Instability in

Table 3.1 Pharaohs who contributed to the Karnak Complex, listed by dynasty and period, and labor contribution represented in cubic meters. Years are in BCE unless otherwise noted (after Clayton 1994/2006; Shaw 2000; UCLA 2008)

	Reign	*Volume (m^3)*
MIDDLE KINGDOM		
Twelfth Dynasty (1985–1773)		
Senruset I	1971–1926	15,700
NEW KINGDOM		
Eighteenth Dynasty (1550–1295)		
Amenhotep I	1525–1504	6,950
Thutmose I	1504–1492	22,050
Thutmose II	1492–1479	10,900
Hatshepsut	1479–1458	9,350
Thutmose III	1479–1425	66,150
Amenhotep II	1427–1401	1,300
Thutmose IV	1401–1391	1,750
Amenhotep III	1390–1352	23,450
Akhenaten	1352–1336	8,350
Horemheb	1323–1295	64,450
Nineteenth Dynasty (1295–1186)		
Ramesses I	1295–1294	50
Sety I	1294–1279	27,650
Ramesses II	1279–1213	2,650
Sety II	1200–1194	1,350
Twentieth Dynasty (1186–1069)		
Ramesses III	1184–1153	14,650
Ramesses IX	1126–1108	650
3RD INTERMEDIATE PERIOD		
Twenty-First Dynasty (1069–945)		
Pinudjem	1054–1039	650
Twenty-Second Dynasty (945–715)		
Shoshenq I	945–924	14,900
Twenty-Fifth Dynasty (747–656)		
Taharqo	690–664	6,750
LATE PERIOD		
Twenty-Ninth Dynasty (399–380)		
Psammuthis	393	16,850
Hakoris	393–380	150
Thirtieth Dynasty (380–343)		
Nectanebo I [a]	380–362	432,400
PTOLEMAIC PERIOD		
Macedonian Dynasty (332–305)		
Philip Arrhidaeus	323–316	100
Ptolemaic Dynasty (305–30)		
Ptolemy III	246–221	1,250
Ptolemy IV	221–205	750
Ptolemy VIII	170–163 & 145–116	2,050
(Unknown Ptolemaic ruler)		13,550
ROMAN PERIOD		
(Unknown Roman ruler)		600

[a] The volume estimates for Nectanebo I represent an outlier in terms of volume and building material and thus are not readily comparable to the building project of other pharaohs

the Twentieth Dynasty helped incite a civil war, and Egypt once again became politically decentralized and territorially divided between the north and south at the onset of the Third Intermediate Period (c. 1069–664 BCE) and Twenty-First Dynasty. Pharaohs in the north ruled out of Tanis, with the south overseen by the Priesthood of Amun. Not all claimed royal titles, however one leader, Pinedjem, stepped beyond the role of high priest and pronounced himself king. At Karnak, he appropriated preexisting sphinxes, inscribed them with his name and relocated them (Blyth 2006, 187; Sullivan 2010, 17). No other rulers of the Twenty-First dynasty, neither from the north nor the south, undertook work at Karnak (Blyth 2006).

Shoshenq I of the Twenty-Second Dynasty consolidated power briefly and added significantly to the Karnak Temple Complex, but his successors were less efficacious. At the end of the Third Intermediate Period, Egypt was finally reunified, but by foreigners: the Kushite rulers from Nubia of the Twenty-Fifth Dynasty (Bard 2007). The Twenty-Sixth through Thirtieth Dynasties are grouped into the Late Period (664–332 BCE). No representatives from the first half of this period added structurally to the Karnak Complex. Although pharaohs native to Egypt ruled the unified state of the Twenty-Sixth Dynasty, they were based at Sais far to the north. The Persians took over in the Twenty-Seventh Dynasty, and again in the Thirty-First Dynasty, and had little interest in acknowledging Egyptian religion. Between these conquests, the Egyptian pharaohs had windows of opportunity to rebuild their control and their stake in important sites such as Karnak (Bard 2007; Blyth 2006). In the Twenty-Ninth Dynasty, Psammuthis built a storehouse, predominantly made of mud brick, instead of stone. Nectanebo I, of the Thirtieth Dynasty, restored many structures and undertook the building of a massive enclosure wall, also composed of mud brick (Blyth 2006; UCLA 2008). Nevertheless, the Late Period ended with Persian rule.

The Egyptians were never autonomous again: Persian rule was interrupted by the invasion of Alexander the Great and the beginning of the Macedonian and Ptolemaic Dynasty (332–30 BCE). The Ptolemies continued to support Egyptian temples and accepted hybridizations of Greek-Egyptian culture and deities. Some of them were interested in leaving their mark on powerful and divine institutions like Karnak, often adding gates and other relatively small modifications to existing structures (Blyth 2006). However, Greeks held all top bureaucratic positions. As Rome rose in power, it also gained control in Egypt. Egypt officially became a Roman province when Augustus Caesar defeated Mark Antony and Cleopatra in 30 BCE (Bard 2007). Traditional culture and religious beliefs were threatened by the pluralism introduced with Roman rule. As Wright (2009, 67) poetically wrote, "Pharaonic Egyptian culture lived and lasted in hieroglyphs [sic]. When this system passed out of knowledge Egyptian culture was dead." The pharaonic tradition of monumental building was at its end.

The nature of Egyptian history was one of punctuated power and consolidation. The pharaonic periods experienced distinct oscillations of

control and disbandment throughout their time. The extraordinary constant was the perseverance of the pharaonic culture. Not until Roman rule did the Egyptian empire finally fall away. These cycles of turmoil, rebuilding, and outstanding prosperity are a testament to the strength of their civilization.

Labor mobilization at Karnak

A major project in the field of ancient Egyptian architecture, and the one from which this inquiry is derived, is the Digital Karnak Project designed by UCLA's Experiential Technologies Center and the Encyclopedia of Egyptology. UCLA's venture is a free, online database consisting most importantly of a three-dimensional digital diachronic model of the temple complex as well as historical information on the pharaohs, architectural terms, and sources of additional material. The data for the present research were calculated and gathered from information posted and provided by the Digital Karnak Project. Much of the background data for this project are available online. Historical information, material data, and building stages are available on the website for public use. Basic dimensional information for each architectural feature is also provided, but these data are insufficient for the more detailed volume calculations needed for this study. Therefore, the UCLA data used were the actual three-dimensional model files used to create the sketches seen on the Digital Karnak Project website. Using Google SketchUp software, we determined the volume for each structure included in the phases of expansion at Karnak.

Volume-based vs. energetics-based modeling

The first step for understanding labor mobilization is to develop an appropriate model that best details the principles of ancient Egyptian human labor activities. For this study, we employed measures of the total stone volume (cubic meters) as a proxy for energetic labor-days to streamline data collection and analysis. This was undertaken for three reasons. First, we observed that published rates of labor for various steps of the construction process were not applicable to Egyptian construction because of missing information about ancient Egyptian building techniques and a lack of experimental testing (cf. de Haan 2009). Second, pharaohs often recycled building materials at Karnak, demolishing the buildings of previous rulers (Blyth 2006), making it difficult to employ an energetics model that utilizes procurement and transportation costs.

Finally, a pilot study of architectural energetics demonstrated that stone volume calculations strongly correlated with labor-days for Karnak building episodes (Drennan 2014, 27). While care must be taken when using a method of volume-based rather than energetics-based calculations, this technique permits us to examine and compare the entirety of Karnak in a

way that would be difficult to do so otherwise. Volume calculations serve as an excellent measure for assigning relative values of political power to the various building episodes at Karnak.

Methodology

To facilitate calculations, a database of volume information was assembled for each architectural feature and the pharaoh who constructed, or relocated, the feature. Table 3.1 includes a summary of these data and Figure 3.3 graphically plots them. After calculating volume totals, it became apparent that there was a severe outlier in the data set. Nectanebo I, of the Thirtieth Dynasty during the Late Period, built a 2000 m mudbrick circuit wall that surrounded the Karnak Complex. This project by Nectanebo I is an outlier because it represents seven times more cubic meters than the next highest pharaonic builder. However, it is important to note that Nectanebo I constructed this wall with quickly manufactured mudbrick rather than stone, a less costly labor endeavor than carved stone masonry. Because Nectanebo I's mudbrick construction dwarfs all the other building episodes (432,400 m^3), we have removed this anomalous building episode from consideration in all subsequent analysis and graphs.

We compared the sequence of labor investment at Karnak against a simplified but comprehensive history of the relevant pharaohs. This brief synthesis of ancient Egypt's history is useful for identifying possible correlations between the labor investment at Karnak and the social power of pharaohs. To understand the reasons why building volume fluctuated over time and how this relates to pharaonic power, we conducted a series of analyses to determine whether particular attributes about a pharaoh's reign made them more likely to invest more labor at the Precinct of Amun. Variables related to pharaonic power used in this study fall into three categories: time, warfare, and centralization. They include: (1) reign length; (2) dynasty; (3) century; (4) warfare; (5) centralization. By compiling information from

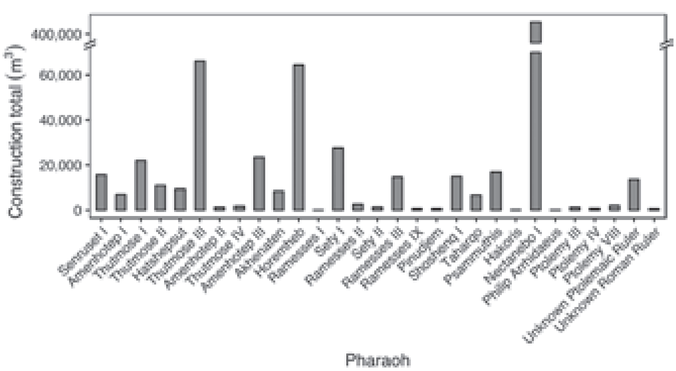

Figure 3.3 Total construction volumes of each pharaoh that contributed to Karnak

Table 3.2 Pharaonic variables utilized in correlations and how they were coded

Variable	*Coding*
Reign length	Number of years based on the most commonly cited dates of reign
Dynasty	Rulers assigned as per past research
Century	Rulers assigned to the century during which the majority of their reign took place
Warfare	
– Participation in	Whether the ruler participated in “defensive”[–1], “offensive”[1], or “no” military activity [0]
– Participants in	If the conflict was between populations in Egypt (“internal”[–1]), between Egypt and an outside force (“external”[1]), or if there was no conflict (“none”[0])
– Location of	“Within” Egypt’s borders [1] or “outside” them [0]
Centralization	Whether the ruler exhibited control over the entirety of Egypt (“yes”[1] or “no”[0])

several sources (Bard 2007; Clayton 2006; Shaw 2000; Vernus and Yoyotte 2003) and using the coding criteria outlined in Table 3.2, the data for each Egyptian ruler was ascertained.

We ascertained relationships between volume totals by running bivariate correlations with each of the pharaonic variables. We compared reign length against the volume sample using the Pearson product-moment correlation coefficient (Pearson’s *r*) as it measures the similarities between two ratio or interval variables. Investigations of variability between all other pharaonic variables and volume were performed using Spearman’s rank correlation coefficient (Spearman’s rho), which measures the strength and form of relationships between ranked ratio, ordinal, or nominal data. All statistical tests were run with and without the extreme outlier (Nectanebo I) to better understand the patterns of correlation.

Limitations

Our analysis emphasizes a reflexive approach to labor investment calculations that mitigates any potential limitations by using a systematic methodology that focuses upon broad trends of mobilization. One potential limitation is related to the nature of the building phases at the Karnak Complex. Twenty-nine pharaohs are recorded as builders at the Precinct of Amun, and the complex went through 2,000 years of continuous construction, modification, repair, and redecoration (UCLA 2008). Structures were destroyed to make room for new building phases or to use as building material. New pharaohs inscribed tales of their success and virtue over the text of their ancestors. Actions like these complicate an already interesting web of building phases. Precision in tracing each pharaonic building phase is accomplished by provenancing decorative motifs and styles, transcribing inscriptions left on structures, stelae, and bricks, uncovering original

foundations, and analyzing artifacts associated with building phases (Blyth 2006; Sullivan 2010). Possible calculation errors are allayed by the fact that the intent here is not to determine the precise amount of labor mobilized by each pharaoh, but to discover broad trends in labor practices through time. Potential recording errors by the UCLA data collectors (see Sullivan and Snyder 2017) are also mitigated by our methodology of focusing upon broad trends in labor practices rather than detailed estimates.

Because the Digital Karnak Project focused on the Precinct of Amun, this study does not consider the entirety of Karnak (see Figure 5.2). Temples dedicated to Osiris and Ptah at the north of the complex were not included in the UCLA database. Two pharaohs, Tutankhamen and Shabaqo, are described on the UCLA site but there are no three-dimensional models associated with them; therefore, volume estimations could not be made for them. There is also a tradition of stelae and statue erection at Karnak that is not included in the three-dimensional structural representation.

Time, warfare, and centralization

Rulers grouped by dynasty and century were statistically correlated with the volume of material constructed as seen in Table 3.3. Clustering pharaohs by dynasty was negatively correlated and statistically significant ($r = -0.487$, $p < 0.009$). Figure 3.4 is a line graph of the spline fit for the construction mean total. The largest building period was during the Eighteenth Dynasty. Over time, dynasties were progressively associated with less construction by volume and investment followed a cyclical pattern that decreased over time.

Grouping pharaohs by century was likewise significant ($r = -0.474$, $p < 0.014$). Figure 3.5 plots the construction total for each pharaoh of a given century; the spline is fit to mean construction total. This plot similarly reveals a peak in labor construction during the fifteenth and fourteenth

Table 3.3 Correlations between pharaonic variables and construction volume totals. Those at a level of statistical significance (< 0.05) are indicated in bold

Variable	*Results*			
	Without outlier		*With outlier*	
	r value	*p value*	*r value*	*p value*
Reign length	0.340	0.089	0.020	0.911
Dynasty	–0.487	***0.009***	–0.396	***0.033***
Century	–0.474	***0.014***	–0.368	0.059
Warfare				
Participation in	0.524	***0.012***	0.342	0.110
Participants in	0.411	0.057	0.422	***0.045***
Location of	–0.514	***0.029***	–0.310	0.196
Centralization	0.484	***0.026***	0.500	***0.018***

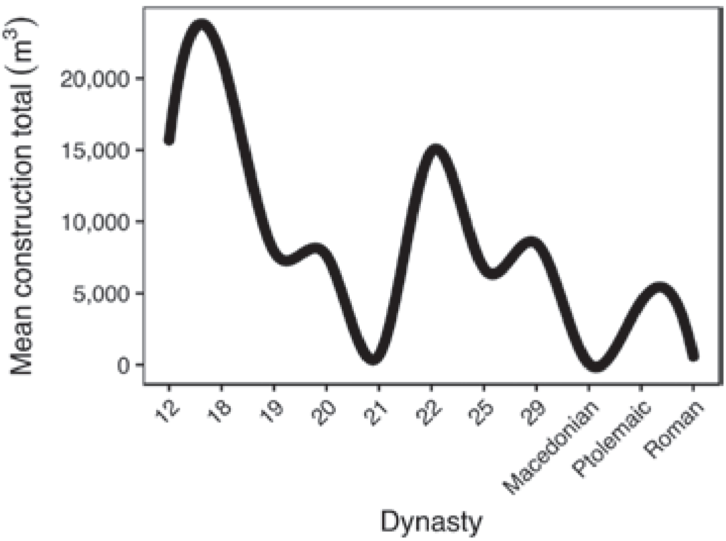

Figure 3.4 Mean construction volume totals by dynasty, showing an early peak in construction followed by cycles of building and an overall pattern of decline

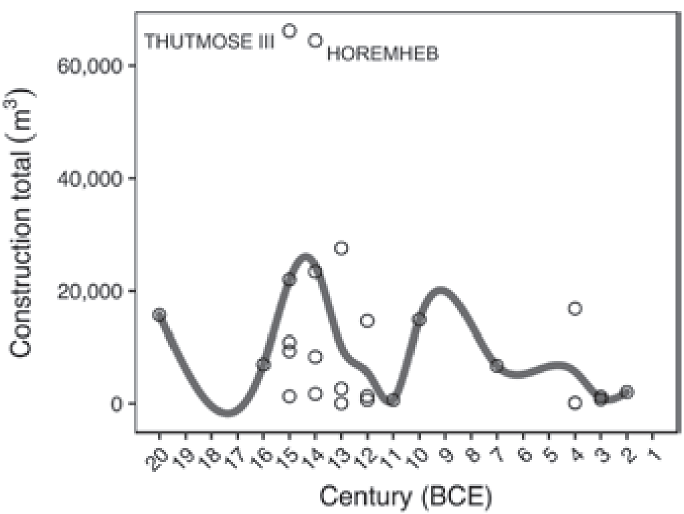

Figure 3.5 Construction volume totals of pharaohs grouped by century. Thutmose III and Horemheb were responsible for the largest building episodes

centuries, bolstered by the construction efforts of Thutmose III (66,150 m^3) and Horemheb (64,450 m^3). It reveals the same pattern of decreased labor investment over time. In contrast, reign length did not correlate with construction volume totals (Table 3.3).

The warfare variable was coded in three ways. Participation in, or avoidance of, military action did correlate significantly with volume totals ($r = 0.524$, $p < 0.012$) in addition to the location of warfare ($r = -0.514$, $p < 0.029$). Figure 3.6 illustrates the amount of building in relation to participation in warfare. There is a marginally significant trend between

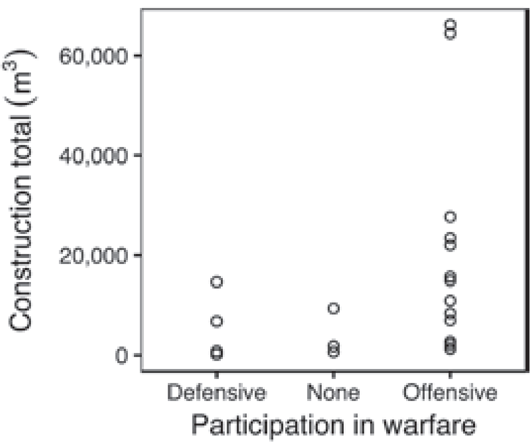

Figure 3.6 Construction volume totals by participation in warfare, which illustrates greater building periods at Karnak during offensive warfare

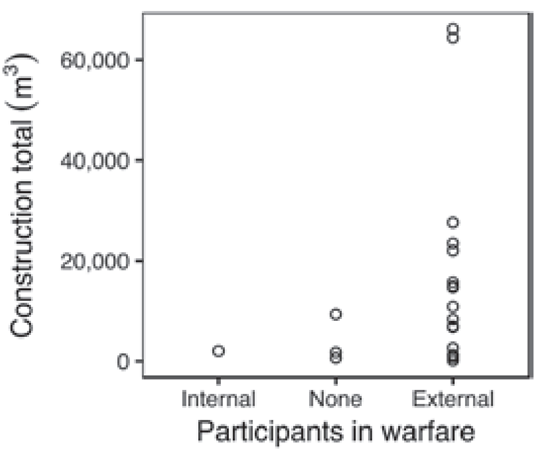

Figure 3.7 Construction volume totals by participants in warfare, which demonstrates a trend of greater dedication to Karnak during periods of warfare with external (non-Egyptian) forces

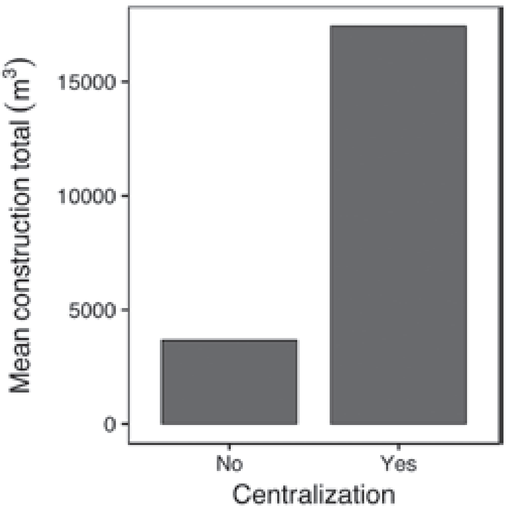

Figure 3.8 Mean construction volume totals by centralization

participants in warfare and the volume of construction during the pharaoh's reign ($r = 0.411$, $p < 0.057$). Reigns with internal conflict (foes within Egypt) were less volumetrically prolific than those with external conflict (foreign forces), although the sample size of pharaohs for internal conflict was very low ($n = 1$). Figure 3.7 illustrates this relationship.

A positive correlation also exists between the centralization of the pharaoh's reign and volume totals ($r = 0.484$, $p < .026$) (see Figure 3.8). The mean volume of construction by centralized reigns is four times greater than the mean volume from less centralized reigns, a considerable gap.

Discussion

These volumetric labor data collected from Karnak reveal three important patterns. First, the statistically significant positive correlation between volume and centralization suggests that government stability and political hierarchy was a requisite for completing complex building projects. This was common in other areas of the eastern Mediterranean, where monumental architecture was associated with hierarchical social status and the capacity to employ surplus labor (Kolb 2014). Monumental architecture requires centralized direction and an immense amount of organization, as well as the resources and wealth to support it. More centralized governments had the level of organization and the authority necessary for such direction. This is clear by the sum of volume devoted by administrations of varying stability. Strong centralized power meant more labor dedicated to the architectural project of Karnak. This connection is especially evident in the political strength of the Eighteenth Dynasty.

Two Eighteenth Dynasty pharaohs were responsible for the largest Karnak building episodes: Thutmose III and Horemheb. Thutmose III rose

to the throne after the death of his father, Thutmose II. As he was only a child at the time of his ascension, his stepmother Hatshepsut was co-regent with him until her death. However, Hatshepsut claimed the title and regalia of pharaoh for herself. A female pharaoh was an uncommon but not unprecedented event. After Hatshepsut's death, some records of her reign were removed from texts and monuments but scholars debate whether and, if so, why this iconoclasm was authorized by Thutmose III. Regardless of his feelings towards Hatshepsut, it is certain that Thutmose III strove to make a mark of his own. He ran ambitious military campaigns into modern-day Syria and Palestine, greatly expanding the Egyptian territories and bringing a tremendous amount of wealth into the country. He set out to, and succeeded in, reinforcing the authority of the Egyptian kingship (Bard 2007). This wealth and stability is still visible in the works at the Karnak Complex.

Horemheb also followed a remarkable leader. As discussed earlier, Akhenaten attempted to completely reorganize the religious and bureaucratic organization of the state, including the adulation of a new god. Even though two pharaohs ruled between Akhenaten and Horemheb (including the famous, young Tutankhamen), Horemheb was the self-proclaimed initiator of a new era (Vernus and Yoyotte 2003). Under his reign, Egypt returned to its former state, with the restructuring of the administration and reopening of temples to Amun. Repairing and expanding Karnak was a large part of this campaign. Once again, the pharaoh exerted his strong control over the entirety of the state (Clayton 2006; Shaw 2000).

Volume also strongly correlates with time, revealing a pattern of early labor efflorescence followed by cyclical decline. This pattern is visible at (1) the broader level of dynasty and century, and (2) the smaller, more individualized scale of reign length. As others have noted, monumental building is often most prolific during a society's formative years, when institutions are taking shape and quickly gaining influence (Kolb 1994, 521; Trigger 1990, 127). Although Egypt was unified for 1,000 years, the greatest amount of investment at Karnak coincides with the beginning of the New Kingdom, approximately 1500 to 1300 BCE, the most prosperous period of ancient Egyptian civilization (Bard 2007).

This early period of intense construction was followed by periods of decreasing labor investment punctuated by pauses in construction. For example, Senruset I began the first significant construction at Karnak during the Twelfth Dynasty of the Middle Kingdom (~1900 BCE). Yet, although Egypt prospered for 1,000 years following Senruset I, the tradition of monumental building at Karnak was not established until later. The decline of the Middle Kingdom and the Second Intermediate Period (~1800–1600 BCE) was marked by the division of power in Egypt and the absence of building at Karnak. Numerous projects began again at Karnak during the prosperity of the New Kingdom Eighteenth and Nineteenth Dynasties (~1500–1200 BCE).

The decrease in building during the Twentieth and Twenty-First Dynasties (~1100–1000 BCE) coincides with the civil war at the end of the New Kingdom that divided Egypt and thrust it into the Third Intermediate Period. The Twenty-Second Dynasty was stabilized by Shoshenq I (~900 BCE); however,

the period following his reign showed an increase in political fragmentation. During the Twenty-Ninth and Thirtieth Dynasties of the Late Period (~300 BCE), families vied for control and superiority. Pharaohs such as Psammuthis and Nectanebo I centralized control long enough to undertake some construction; however, the Late Period ended with a Persian takeover. The last small resurgence of architectural investment occurred during the Ptolemaic Period (~200–100 BCE). Rulers from this dynasty continued to support Egyptian temples, melding Greek and Egyptian deities and culture (Bard 2007, 294). For their Roman successors, Egypt was simply a province, and the status of the Egyptian priesthood diminished. As pharaonic Egyptian culture became obsolete under Roman rule, so did the tradition of monumental creation and repair (Wright 2000, 67). On a smaller scale, reign length did not correlate with the amount of volume attributed to individual pharaohs (see Table 3.3), suggesting that rulers did not build more simply because they may have been in power longer. This point is important because it facilitates alternative explanations for the quantity of pharaonic building.

Finally, there are strong statistically significant correlations between stone volume and conflict. During periods of conflict within Egypt or periods that saw little military action at all, building at Karnak was minimal. Those rulers who invested in offensive, foreign military campaigns were linked to larger building phases. One reason monumental construction correlates with war efforts is that it may have created an aggrandizing or promotional effect on society for both the war and the ruler. The capability of pursuing such large projects at Karnak during times of conflict abroad may have been an assurance to the population of a ruler's adeptness and control in the situation; that is, a justification that conflict had not interrupted life in Egypt, and that their pharaoh still had power and the grace of the gods. As Egyptian rulers lost religious roles in society over time, emphasizing their military might became more important. Building during foreign wars not only demonstrated a ruler's power but also continued to celebrate the power of religion and the architectural pursuits associated with it.

Another explanation is that successful campaigns with foreign armies often resulted in large amounts of incoming tribute that would fund building projects. Particularly during the Eighteenth Dynasty, Egypt became very wealthy through war. However, times of peace could also be affluent, as under Amenhotep II and III during the Eighteenth Dynasty (Bryan 2000; Clayton 2006, 115). In addition, although most military action would have been costly to the state, internal dispute could have been even more costly in many ways. War between populations within Egypt would drain the economy, but also affect civilians more directly by disrupting daily life. The building of unnecessary monumental structures would likely not have been the priority for pharaohs under such duress. Such would be the case as well for pharaohs under attack by foreign forces within Egypt.

The volume/centralization and volume/conflict correlations indicate two distinct strategies of leadership. The first pattern involved the surge of investment during the New Kingdom, indicating that rulers may have

specifically invested in sacred spaces such as Karnak during this formative and centralized period. The temple complex would have been an important outlet for building their public perception, a necessary asset of the ideological and coercive side of social power. The prestige garnered by dedicating resources to the temples would have been essential for these ambitious pharaohs. It established their authority and inspired confidence in their rulership. The second pattern was that of cyclical decline. Periods of stability coincided with investment and these phases of investment abated over time. Rulers dedicated time and energy to the Karnak Complex when the nation was stable, building monuments used for self-aggrandizement and personal commemoration. Likewise, such projects would have served as important propaganda during times of offensive warfare abroad.

Conclusion

Labor investment analysis provides us with a tool to quantify and comparatively analyze sociopolitical authority. This connection can be made because the successful completion of a project demonstrated the ability of the leader to organize such an enterprise and recruit a huge number of citizens to work towards a politically strategic goal that was not directly beneficial to them. Not only did the realization of the project itself display the sheer authority of the pharaoh, but the finished product also served as a physical, lasting reminder of his might. As Trigger (1990, 122) notes, "Monumental architecture makes power visible and hence becomes power rather than merely a symbol of it." Architectural pursuits, such as the temples of Karnak, reinforced the ideological and political superiority of the pharaoh as they exhibited monopolization of religious and social meaning.

The amount of material commissioned by a pharaoh is connected to their social power as based on the stability and centralization during their rule. Stable control over political administration, command of the military, and ideological dominance all contribute to social power. Rulers with greater power confirmed it through their successful building programs at Karnak. Likewise, it served as a justification for their authority, their role, and military actions. Karnak is one site of many but it is an extensive and paramount one in the history of Egypt. Its 2,000-year narrative of construction and alteration proves that its value is enduring, not limited to a certain period or pharaoh. Although this investigation only examined the Karnak Complex, it greatly increases the confidence that similar results will be found for monumental building projects across Egypt.

Acknowledgments

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4 An energetics approach to the construction of the Heuneburg

Thoughts on Celtic labor cost choices

François Remise

Introduction

By the beginning of the first millennium BCE, Celtic peoples occupied large portions of Western and Central Europe and built burial mounds and dwelling sites. While long recognized as an integral element of the archaeological landscape, to date few studies have estimated the amount of labor and time involved in these construction projects. In this chapter, I present an analysis of the labor and time spent to construct the buildings and earthworks of the Heuneburg site in southwestern Germany between 600 and 540 BCE using the architectural energetic approach previously outlined (Abrams and McCurdy, Chapter 1). In the present study,[1] I focus particular attention on the issue of labor cost choice for each task in each construction project.

The Celts in historical context

The first references to the Celts in ancient literature date from the sixth and fifth centuries BCE (Hecataeus of Miletus and Herodotus). Since the end of the nineteenth century, archaeologists have articulated the findings of archaeological excavations with the ancient texts to generate a general chronology of the Iron Age in the North Alpine region. Two main periods have been identified: the First Iron Age (800 to 450 BCE) mainly corresponding to the Hallstatt culture, and the Second Iron Age (450 to 50 BCE), mainly corresponding to the La Tène culture.

During the first part of the First Iron Age (800 to 630 BCE), a common aristocratic culture emerged, characterized by burial mounds containing iron swords and horse harnesses. Around 630 BCE, a series of power centers called *Fürstensitze* (princely seats) developed north of the Alps, likely due to the intensification of commercial trade routes around the Rhine and Danube valleys. These princely seats are characterized by dense fortified settlements, probably controlling large territories, and surrounded by huge funeral mounds. The deceased were buried in tombs under tumuli always accompanied by a four-wheeled wagon and rich bronze vessels similar to Etruscan drinking vessels. The princely seats phenomenon reached its

peak in the first half of the sixth century BCE, parallel to the height of the Heuneburg princely seat.

The Heuneburg site

The Heuneburg site is located along the Upper Danube River in southwestern Germany. It is one of the most important archaeological sites of Early Iron Age Europe, represented by a large residential settlement as well as many nearby burial mounds (see Figure 4.1). A mudbrick fortification, built to protect the densely populated hilltop residents, was set on a stone foundation.[2] Unique north of the Alps, the mudbrick fortification replaced an earth and timber rampart around 600 BCE. This hill fort however was only part of a far larger settlement of 100 ha comprised of a lower town and an outer settlement divided into quarters by a system of banks and ditches. The population of this settlement has been estimated at 5,000 inhabitants (Kurz 2012, 19–20), making it one of the first urban settlements in Western Europe. Finally, the concentration of burial mounds in this area, including the Hohmichele (30,000 m^3), makes it an exceptional site (see Figure 4.2). The mudbrick fortification was violently burnt around 540 BCE, and the site was finally abandoned in the middle of the fifth century BCE.

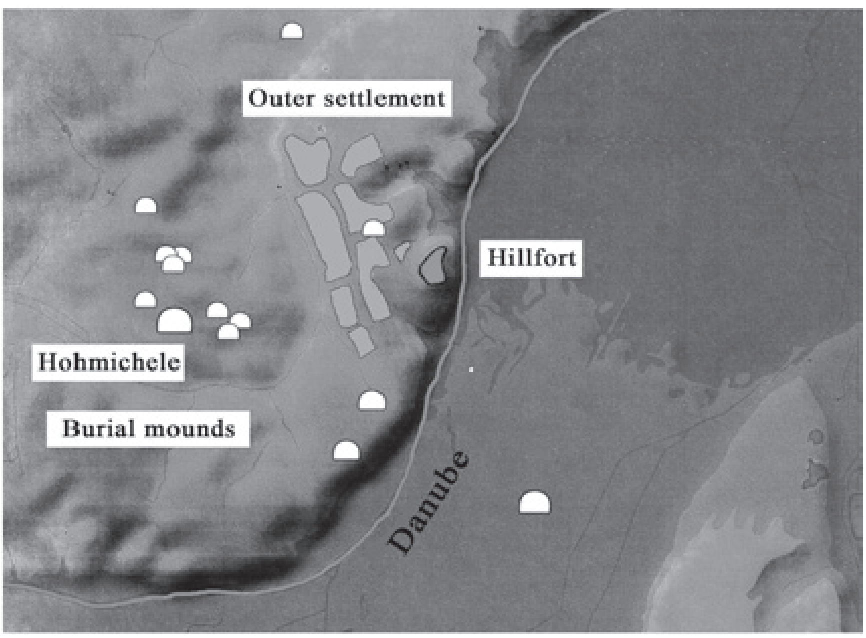

Figure 4.1 The Heuneburg site

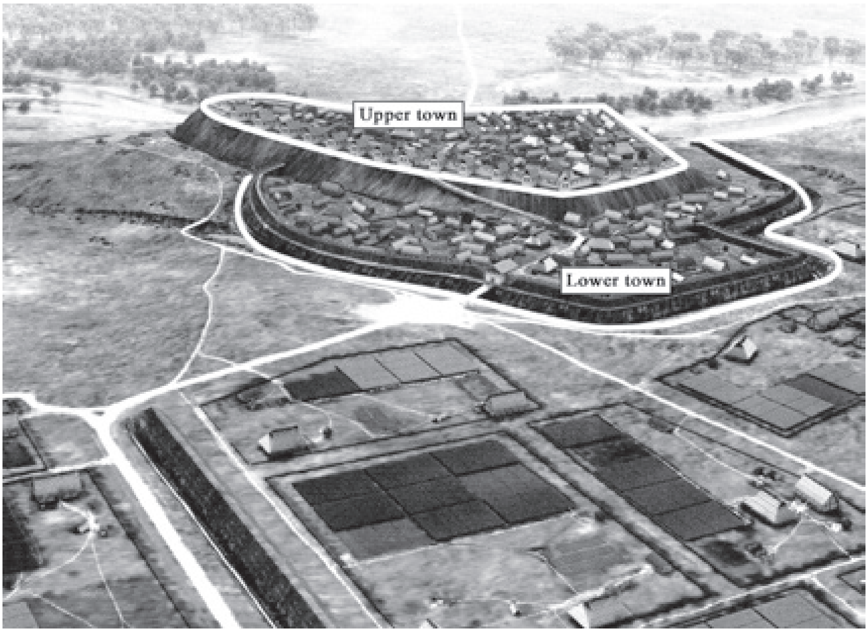

Figure 4.2 The Heuneburg reconstruction

Energetics assessment overview

The objective of this ongoing study is to estimate the most likely balance of labor and time that the community of the Heuneburg expended in constructing the buildings and earthworks in the 60 years between 600 and 540 BCE. These building efforts include the fortifications, houses, banks, and ditches of the town, and of the outer settlement as well as the burial mounds. As is the standard protocol in these studies, I began by identifying the raw materials in the targeted buildings and calculating their volumes. Then, for each task in the construction process, I chose the most likely value of labor, taking the worksite conditions into account (e.g. material characteristics, manufacture and construction methods, tools, motivation). The raw materials and their volumes were identified and measured from the site excavation reports spanning some 50 years (Gersbach 1995; Riek 1962). For each construction project, a detailed analysis of labor included 17 main tasks, more than 30 basic tasks for the mudbrick fortification, and 3 tasks for the Hohmichele burial mound. For each task, I collected and evaluated as many published values as possible including experiment reports (several dozen), former energetics studies (more than 100), and nineteenth-century building manuals. In this chapter, I detail the method I used to choose appropriate labor cost values.

Choice of labor cost values

Due to the inherent uncertainty in energetics approaches, at best we can only obtain an order of magnitude in our estimation of building construction costs. However, when one closely considers the labor cost value options for each task, this uncertainty is significantly reduced. Most of the previous architectural energetics studies consider between one and three cost values for each task, and seldom more than five values. The final cost value chosen is typically any one of these values, an interpolation[3] or average value, or an extrapolation of these values, which qualitatively factors in variability of cost.

In this study, I describe a new approach.[4] First, I identify and assemble as many cost values as possible (from ten to hundreds of values) for each task. Second, I find the key factors that explain the scattering of the values (e.g. type of manufacture, importance of the project, daily hours worked, etc.) and quantify the influence of these factors. Finally, I choose the value representing our best estimate according to these key factors. I demonstrate this method through two examples: the manufacture of mudbricks and human transport (see Figure 4.3).

Manufacture of mudbricks

The manufacture of mudbricks at Heuneburg involved several stages: (1) procurement of the raw materials (earth, straw, water); (2) mixing of the raw materials; (3) molding of the bricks (including workshop setup); (4) drying of the bricks (turned on alternating ends for several days); (5) stacking. Here, I comparatively assess the manufacturing times included in stages 2 to 5. The manufacturing time is strongly influenced by the manufactured volume. I have

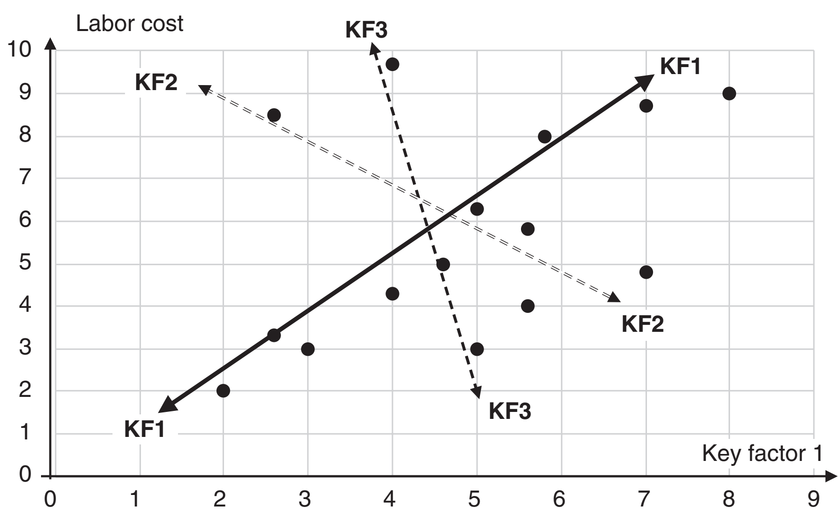

Figure 4.3 Key factors

found 32 values in the literature, but I have only selected those nine that allow us to infer the cost per volume. I did not take the values expressed only in numbers of bricks into account, per hour or per day; nor those provided through unclear personal communication. No values found in ancient texts have been considered because the conditions in which these values were generated were either imprecise or missing. The number of available values is too low to allow the construction of a precise model; however, I can bring to light some key factors and evaluate their influence. The nine selected values (corrected for eight working hours and no supervision included) are included in Figure 4.4.

Experiment 2 was carried out very quickly: no binding agent was necessary thanks to ready-to-use earth and a very quick drying time (one day). In spite of inexperienced workers, the productivity is high. Experiment 5 was carried out with both a very inexperienced supervisor and inexperienced workers. The very low manufacturing time confirms, if such confirmation were necessary, that there is no lowest rate. Experiment 7 corresponds to a production process involving a double mold with a bottom. This method is very time-consuming. The objective of Experiment 8 was to show the low cost of mudbrick constructions. The cost constraint and the use of "modern" tools (wheelbarrow, water pump, molding press) explain the higher productivity of this large project. The conditions of Experiment 9 (partial reconstruction of Hattuša city wall) are very precisely described. I consider that the workers had a relatively low motivation.

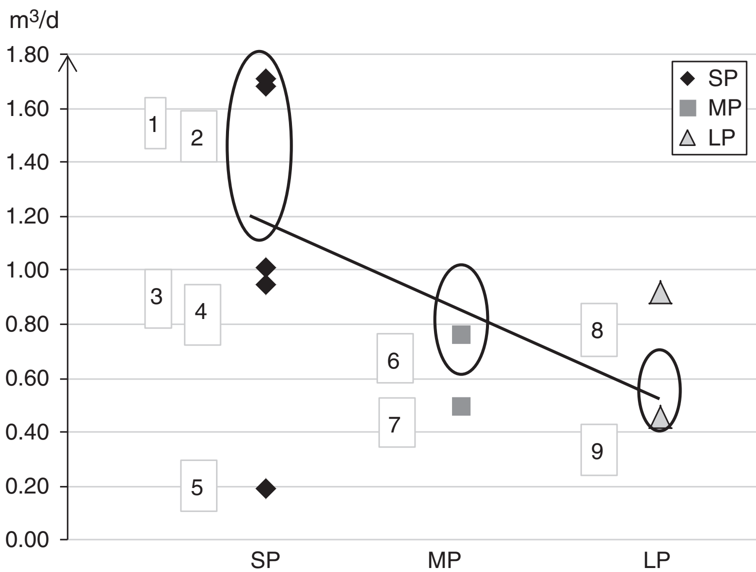

Figure 4.4 Mudbricks manufacture experiment values. SP, MP, and LP correspond to Small, Medium, and Large Projects. Values included in this comparison derive from the following sources: value 1 (Mallowan 1966, 53); value 2 (Gelin 2010, 445); value 3 (Smailes 2000, 37); value 4 (Dalokay 1969, 119); value 5 (Walsh 1980, 17); value 6 (Eeckhout 2000, 203); value 7 (Papadopoulos 2008, 695); value 8 (Fathy 1989, 200); value 9 (Seeher 2007, 213)

In spite of the low number of experiments, I can draw one clear conclusion: the manufacturing time is highly dependent on the project size. More specifically, as the project size increases, the rate of mudbrick manufacturing decreases. The large surface areas necessary to both mix the earth and dry the bricks impose extra walking time to mix the earth, to turn bricks, and to create stacks (e.g. see Figure 4.5). Other factors also explain the lower efficiency of a large project including the difficulty and time to relay information, longer transportation distances, the leveling of individual capacities, and the difficulty to create and maintain the team's motivation. Furthermore, to optimize the effectiveness of a large project, it is necessary to organize supervision of the project with roughly one foreman for every ten workers.[5] This will reduce the rate of mudbrick manufacturing even further.

Figure 4.6 compares the manufacturing values generated from 13 energetics studies relating to mudbricks (no supervision included), which can be compared with the nine experiment values (see Figure 4.4). There is a factor greater than eight between the highest and the lowest values compared in Figure 4.6. Only values 11 and 13 correspond to the experimental values. I assess these values as follows. Value 1 is too low and based on a problematic calculation. Values 2, 3 (derived from value 2), 4, 6, and 10 are too high while value 12 is too low. They result from poorly interpreted calculations based on rates of numbers of bricks per hour. Value 5 is an average of six published values that does not include the experimental values 3, 5, 6, 7, and 9 mentioned before (which would significantly lower the average). Value 7, based on a small *in situ* experiment, is too high for a large project. Value 8 was simply a guess estimated by doubling the value corresponding to the mixing of the earth. Value 9 was estimated from small project rates and is a bit too high.

Figure 4.5 Mudbricks manufacture in Peru

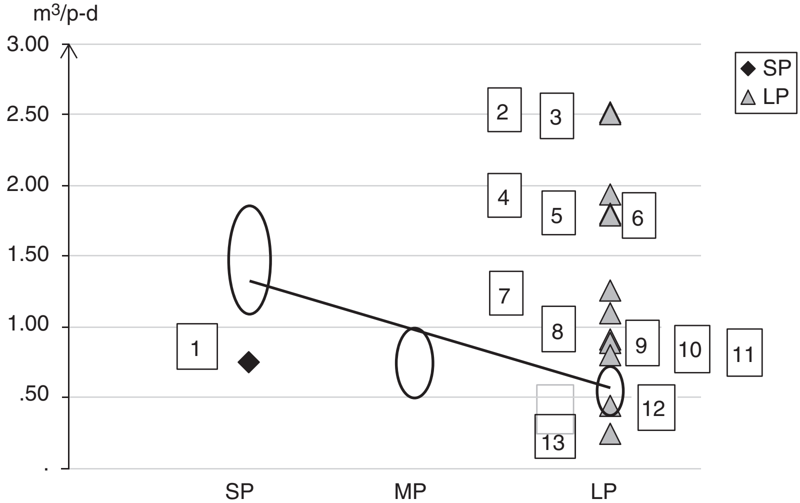

Figure 4.6 Mudbricks manufacture values in energetics studies. Values included in this comparison derive from the following sources: value 1 (Devolder 2013, 37); value 2 (Homsher 2012, 17); value 3 (Drennan 2014, 30); value 4 (Burkhardt 2010, 34); value 5 (Burke 2008, 145); value 6 (Gelin 2010, 445); value 7 (Arnold 1987, 90); value 8 (Murakami 2010, 203); value 9 (Smailes 2000, 37); value 10 (Bielinski 1985, 61); value 11 (Eeckhout 2000, 203); value 12 (Ormeling 2011, 20); value 13 (Seeher 2007, 219)

As the scale of the project increases, the rate of daily work decreases. As evident in the case above, the labor cost of mudbrick manufacture (supervision not included) should be chosen in a range of values from 1.10 m^3/p-d to 1.80 m^3/p-d for a small project, from 0.60 m^3/p-d to 1.00 m^3/p-d for a medium-sized project, and from 0.40 m^3/p-d to 0.70 m^3/p-d for a large project. The other assumptions of the project (daily hours worked, type of manufacture, tools used, workers' motivation, etc.) will be compared to the conditions of published experiments, and the more appropriate value will be chosen within the ranges of values. Currently, most of the values used in energetic studies are obtained through short experiments on small projects, suggesting that the labor cost for large projects may be underestimated in most cases.

Human transport

A second major set of cost values that can be similarly assessed relates to human transport of light loads. Previous architectural energetic studies refer mainly to two sources of data: (1) the ECAFE (1957) formula, first applied by Aaberg and Bonsignore (1975) and more broadly adapted by Abrams (1994) and (2) a transport value derived through replicative experiments (Erasmus 1965, 284–289).

The ECAFE formula

The ECAFE (1957) formula is as follows:[6]

$$Q = H/q \times 1/(L/V + L/V' + c + d + e)$$

It is often assumed that this formula was derived from UN experiments. However, without assigned values for the variables, this formula is nothing more than the mathematical expression of the relation between these variables; it is not the result of experiments. Aaberg and Bonsignore (1975, 47, 55–59)[7] simplified this formula by eliminating the factors c, d, and e.[8] Further they assigned the following values of q = 40 kg, V = 3 km/h, and V′ = 5 km/h without justifying these values.[9] Since then, this formula has been consistently used with the values V = 3 km/h, V′ = 5 km/h, and a value for q between 15 kg and 40 kg.[10]

Erasmus' experiments

Many energetic studies rely upon transport cost values derived from Erasmus' (1965) experiments (see Table 4.1). However, these experiments, although heavily relied upon in energetics studies, are limited in several ways: (1) only six transport tests were conducted for only one day of five or six hours; (2) each test differs one from another on two, three, or four of the five factors used: person, lead (distance), load, method of transport (on the shoulder, on the head, tumpline method). This prevents us from quantifying the influence of these factors. The only way to profit from these experiments should be to use the average speed (around 4.2 km/h) for any distance from 50 to 1,000 m, and for any load between 20 and 34 kg.

Most often, researchers choose the value that corresponds to the lead they measure or assume in their study. For 50 m, they consider a 4.1 km/h velocity and a 20 kg load; for 750 m, they consider a 4.5 km/h velocity and a 34 kg load. Yet these two results are clearly inconsistent (Erasmus 1965, table 3); the second one reflects a much better performance than the first (153 kg × km/h compared with 82 kg × km/h).

"Men Who Move mountains"

Two UN reports (ECAFE 1957; UN 1961) detail extensive experiments that were carried out in Asia. This resulted in a third report by the International

Table 4.1 Erasmus' experiments. The values correspond to five hours worked a day

		Lead (m)	*V_a (km/h)*	*Load (kg)*	*Transport*	*kg × km/h*
Sonora	1	50	4.1	20	shoulder	82
	2	100	4.6	20	shoulder	93
Tikul	A	250	3.4	28	head	95
	B	500	4.0	25	tumpline	100
	C	750	4.5	34	tumpline	153
	D	1,000	4.4	23	tumpline	101

Labour Organization titled *Men Who Move Mountains* (International Labour Office 1963). This report offers a wide range of human transport data. During a dam construction in India, eight civil engineers collected more than 45,000 measures. They observed 6,500 men and women digging and transporting earth during a one-month period.

The earth was carried on the top of each porter's head and loads were transported using a relay method. Laborers worked between 9 and 11 hours per day, with effective working hours of 5.3 to 7.8 hours, in temperatures in the 27–39°C range (81–102°F) in the open sun. These measures allow one to quantify the influence of the tools used, the lengths of the leads, the various slopes (up and down), the loading, unloading, and rest times, and the speeds according to the loads. A superior performance by one group of workers – the Malabars – emerged since they took advantage of a much higher daily calorie intake. When compared with the results of the Erasmus experiments on level ground, we note that the daily outputs of the Malabar workers were much higher than those of Erasmus' Maya workers. The Malabar workers walked faster (4.65 km/h), but more importantly, they carried heavier loads (38 kg) and worked longer per day (7.8 hours). In addition, the daily outputs of the other workers (including women and children) were also higher than those of Erasmus' workers, with the exception of the "C" worker. A comparison of these values is presented in Figure 4.7.

As both examples of cost value assessments presented here show, an informed choice of cost values should be based on a maximum number of available values. While the present volume (see Table 1.1) begins to create a comprehensive corpus of available labor costs, additional data from

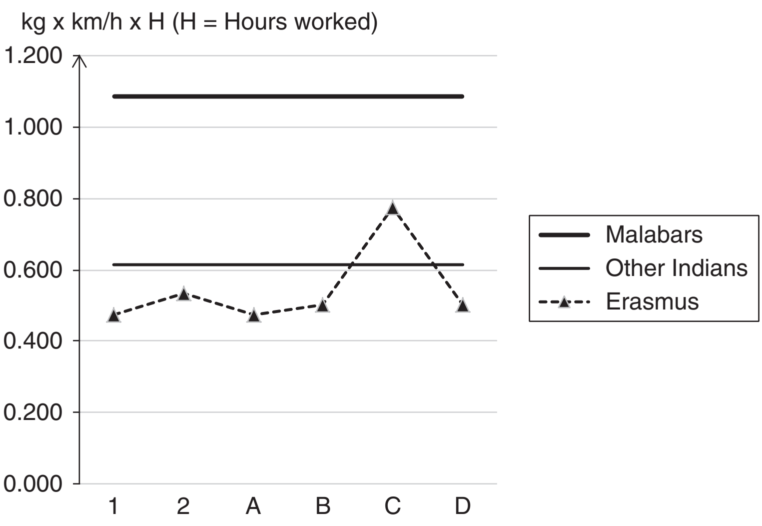

Figure 4.7 Indian values compared to Erasmus' values

these reports should be considered in future studies. Analytical experiments should be scheduled, especially when reconstruction programs are foreseen. The credibility of energetics studies relies on a large data collection program of the published values and in the scheduling of experiments with rigorous experiment protocols. In the particular case above, it would be better to use values derived from the Indian report rather than from the Erasmus experiments. The average load should be derived from measures of basket-loads as seen on the archaeological site. Without site data, reasonable values should be derived from the Indian report. The velocity taken into account should be dependent on the assumed load, and within a 4.0–5.0 km/h range if the workers' motivation is "fairly high." Any other value (lower) is acceptable, taking assumed conditions of the site into account (festive environment, rituals, transport by women and children, etc.).

The energetic assessment of the Heuneburg site

First, I quantify the mudbrick fortification of the Heuneburg. The relevant labor construction volumes and cost values are presented in Table 4.2. All values are rounded and include waste and supervision. They result from calculations detailed in greater depth elsewhere.[10] Here I describe more fully the applied cost estimates for mudbrick manufacture and transport as these two elements represent two of the largest costs in constructing the Heuneburg.

Table 4.2 Mudbrick fortification labors cost values

Mudbrick fortification	*Volume (m^3)*	*Labor cost*	*Time (p-d)*
Design and organization			800
Demolition of the former rampart	8,400	2.4 m^3/d	3,500
Excavation and facing of the stones	1,200	0.9 m^3/d	1,200
Stone transport (oxen carts)	1,200	0.2 m^3/d	6,000
Stone base construction (stones + mortar)	1,400	0.6 m^3/d	2,200
Mudbrick manufacture*	8,050	0.3 m^3/d	25,000
Mudbrick transport	8,050	0.4 m^3/d	17,800
Mudbrick laying (+ mortar)	8,500	0.6 m^3/d	13,100
Mortar and plaster manufacture	1,500	1.0 m^3/d	1,500
Mortar and plaster transport	1,500	0.5 m^3/d	3,100
Plaster application	9,300	8.5 m^2/d	1,100
Wood structure manufacture	600	0.07 m^3/d	8,600
Wood elements transport	600	0.4 m^3/d	1,400
Wood structure laying	600	0.2 m^3/d	3,300
Ancillary works			2,200
Site cleaning			200
Supervision			9,000
TOTAL			**100,000**

* Including mixing of the mud, workshop building, mudbrick manufacture and stacking

Mudbrick manufacture

Around 600 BCE, the climate at the Heuneburg was as it is now. Therefore, the mudbricks could not have been manufactured outside of the June to September period, and even during this period, it rains at least every other day. Thus, the workshops had to be covered (Gersbach 1995, 35–36) so that the mudbricks could dry under shelter (for at least ten days).[11] Considering the uncertainty of the drying time, I estimate minimal manufacturing and minimal drying (ten days) times, considering optimal manufacturing conditions. I consider that the value of experiment 9 (Hattuša), 0.44 m^3/p-d, is the most acceptable value. The longer drying time at the Heuneburg would be offset by the workers' greater motivation.

To manufacture the 545,000 mudbricks (8,050 m^3) needed for the construction, I assume that 20 covered workshops were built along the streams around the Heuneburg hill. I tested various assumptions on covered areas, storage heights, and production plans during one or two seasons and chose an optimized solution. Mudbrick manufacture was conducted during two seasons (from June to September). Twenty workshops were built. Each workshop consisted of: (1) a covered production building (32 × 16 m) containing 60 rows of 30 mudbricks (each measuring 48 × 41 × 7.5 cm); (2) two storage sheds (30 × 3 m); (3) a pit measuring 21 × 19 m. Further, this production building would be built on wooden poles with a thatched roof.[12] It would serve to shelter the molding and drying areas and was designed to shelter ten days' of production.

The pit was designed to provide 500 m^3 of loam at a 1.25 m depth. In 1 day, 6 persons could manufacture 2.64 m^3 of mudbricks (labor work rate[13] 0.44 m^3 multiplied by 6 laborers). In 3 months, the 6 persons could manufacture 253 m^3 of mudbricks (2.64 m^3 multiplied by 96). If these mudbricks were stored 2.14 m in height (24 layers of mudbricks on planking), the necessary storage area is 141 m^2 (253 divided by 1.80). I have considered 2 covered stacking areas measuring 30 × 3 m (see Figures 4.8 and 4.9).

Within each workshop, there was a distinct organization relating to the process of manufacture. When the loam is ready, three persons mold the bricks, each one delivered by one person. The mudbricks are then laid out for drying, beginning at the end of the production area. After five or six days, they are turned over and laid on their opposite face for two days. Then they are put upright on one edge to finish drying. In ten days, six persons manufacture 26.4 m^3 (6 × .44 m^3 × 10) or 1,789 mudbricks. On the 11th day, the bricks manufactured the first day are put in one of the stacking areas and the surface is freed for the manufacture of the day. Every day, this operation is repeated.

At the end of the first work season, 4,060 m^3 of bricks (20 × 253 m^3) were manufactured. At the beginning of the second work season, 2,990 m^3 of bricks would have to be manufactured, comprising 57 days of work

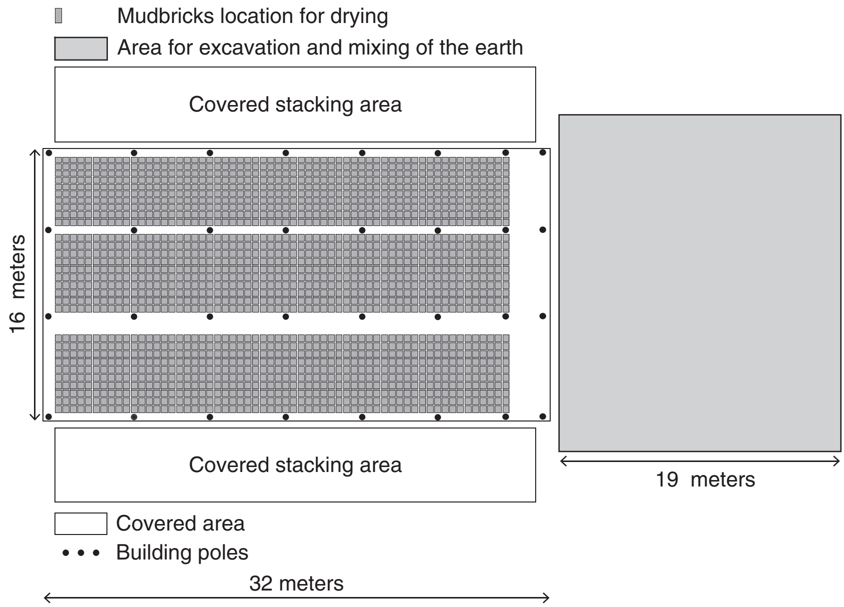

Figure 4.8 Mudbricks workshops

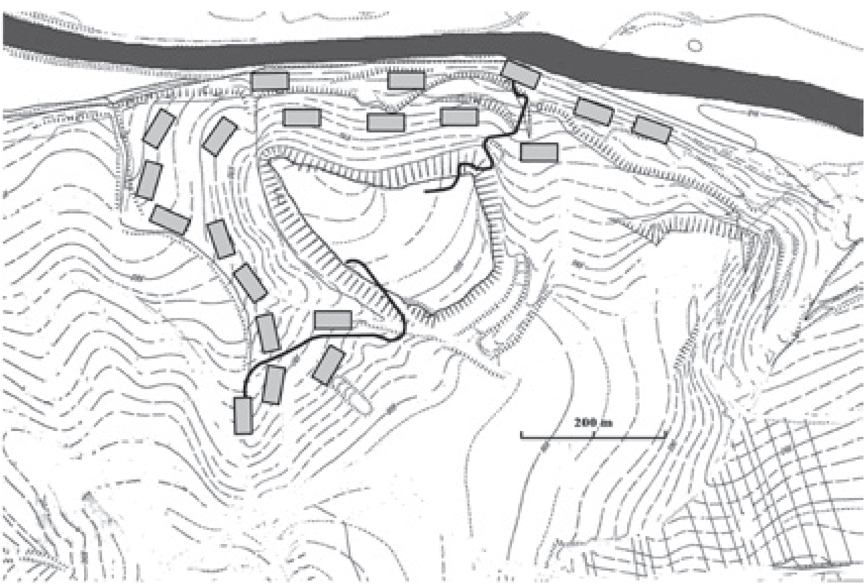

Figure 4.9 Workshops layout model

among the 20 workshops. Based on these cost estimates, mudbrick manufacture would have required approximately 25,000 person-days (see Table 4.3).

Mudbrick transportation

The average trip between the workshops and the stacking area near the fortification can be modeled as shown in Figure 4.10. I suppose that the mudbricks were transported using the relay method and I rely upon the velocities from the mentioned report for the "Other Indians" and for the indicated slopes (International Labour Office 1963, 157–158). The load is 25 kg corresponding to the weight of one mudbrick. If I use 5.3 hours worked daily,[14] then each worker transported 30.5 mudbricks per day.[15] Therefore, the total transportation time would be 17,850 p-d.[16]

Maintenance of the fortification

As the objective of the current study is to estimate the total construction time of all the works done by the Heuneburg community between 600 and 540 BCE, the time required to maintain the fortification during that period is also relevant. A partial reconstruction of the fortification was done following a fire around 560 BCE. I estimate the reconstruction time to be 1/5 of the construction time, that is, 20,000 p-d. The sustainability of a mudbrick construction requires the renovation of the walls' protective coating,

Table 4.3 Mudbrick fortification labor cost

	Volume (m^3)	*Unit cost value (m^3/p-d)*	*Labor cost (p-d)*
Earth excavation	9,000	2.80	3,200
Straw and water			300
Mudbrick manufacture	8,050	0.44	18,300
Workshop construction			3,200
Total mudbrick manufacture			**25,000**

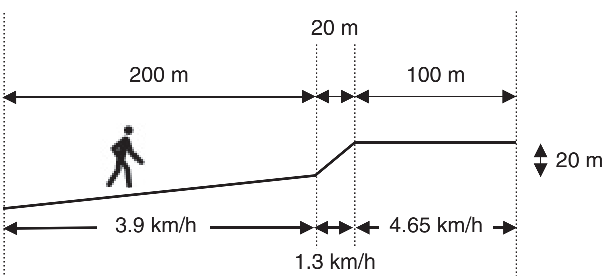

Figure 4.10 Mudbrick transportation velocities

especially given the Heuneburg's wet climate. I assume that 60% of the coating was renovated every year, which required 85,000 p-d over 60 years. Mudbricks and wood structures would have also been renovated, which required 15,000 p-d over 60 years. The total investment in maintenance of the fortification is then estimated at 120,000 p-d.

Comprehensive energetic estimates

The fortification of the lower town is not well known, but it was probably built with earth. I estimate the cost to build it at 20,000 p-d and the maintenance at 10,000 p-d over 60 years. Excavations have identified and characterized the buildings of the upper and lower towns and of the outer settlement (houses, workshops, barns) (Gersbach 1995, 95–173). All these are quadrangular and were built completely of wood. There are three types of buildings: load-bearing wood posts buildings, buildings with sill-beams, and *blockbau* buildings. Surprisingly, the lifespan of the upper and lower towns' buildings did not exceed 15 years since humidity in this region causes wood posts and sill-beams to rot quickly (Gersbach 1995, 130).

In each of the excavated areas, I have calculated the buildings' density and the buildings' areas and types. When extrapolated to the whole inhabited area, I have estimated that all the buildings were equivalent to 740 buildings of 36 m^2 each. I estimate the time to construct all the buildings and ancillary works such as ditches and fences at 35,000 p-d and their reconstruction in the 60-year period at 96,500 p-d.

In the Heuneburg area there are many burial mounds, four of which are among the largest in Europe. The most important burial mound, called the Hohmichele (30,000 m^3), was constructed between 600 and 540 BCE. Following excavation, 13 tombs were identified (Riek 1962, 6).

I have estimated the time to construct the Hohmichele and then extrapolated this result to all the burial mounds proportionate to their volumes. Since we do not know the source of the earth and thus transport distance, I calculate the minimum time to construct the Hohmichele assuming the earth was excavated as close to the mound as possible but then increased this value by 10%.

I have assumed that the basket load was 20 kg and have considered the sloped lead section to calculate the average speed as illustrated in Figure 4.11.[17] Table 4.5 provides estimates (rounded) of the costs of tasks involved in constructing the Hohmichele (considering an eight-hour workday). When extrapolated to all the burial mounds of the period, I obtained the speculative overall cost of 150,000 p-d for the burial mounds (see Table 4.4).

All the labor cost estimates for construction at the Heuneburg are summarized in Table 4.5, distinguishing the involvement by the community (fortifications), the clans (burial mounds), and the families (private buildings). The total effort spent over 60 years calculates to an average of 8,867 p-d per year, which is equivalent to the working time supplied by 60 persons in

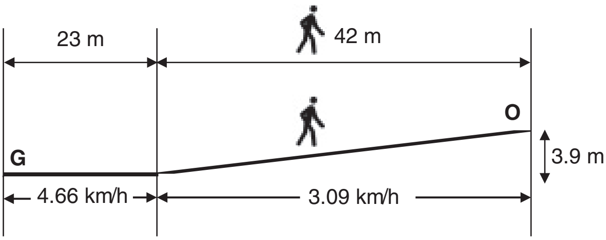

Figure 4.11 Hohmichele transport velocities

Table 4.4 Hohmichele labor cost

	Labor cost (p-d)
Excavation of earth	9,500
Transport of earth	20,500
Ramping of earth	5,000
Supervision	1,000
Total	**36,000**

Table 4.5 Total construction time

Time spent at the Heuneburg between 600 BC and 540 BC		*First construction*	*Maintenance and reconstruction*	*Total*
Community	Upper town fortification	100,000	120,000	250,000
	Lower town fortification	20,000	10,000	
Clans	Burial mounds	150,000		150,000
Families	Private buildings	35,500	96,500	132,000
Total (times in p-d)		**305,500**	**226,500**	**532,000**

five months. Compared to the total population of the community, this dedicated workforce seems very reasonable. If my assumption that the fortification of the upper town was constructed in two work seasons is correct, the dedicated workforce must have been higher than 400 persons at the peaks, while an important workforce was needed for agricultural works. An additional workforce would have been needed from outside of the Heuneburg community. The political prominence of the Heuneburg could have made it possible (Buchsenschutz 2015, 116–118).

Conclusion

Broadly, the analysis presented herein is an example of one way to advance the use of architectural energetics in archaeology. It is important to amass and analyze as many values per task as is possible to identify and quantify

those factors that account for differences. These differences in labor cost values can be significant, and thus significantly affect person-day estimates which are derived from them. By considering a wide range of costs, we realize that there is no "standard cost" for a task. Also, choosing a value that exactly corresponds to an experiment provides only an illusion of a guarantee. As architectural energetics moves forward, labor costs should be chosen from a continuum of values. As more work is undertaken to expand the labor cost values available to architectural energetic analysis, we will have more values from which to choose to conduct analyses that are as contextually appropriate as possible.

Acknowledgments

This chapter is a shortened version of my master's thesis. First of all, I want to thank Stéphane Verger who guided me during this thesis, Jean-Paul Guillaumet for his wise technical comments, Roberto Tarpini for his information on the Heuneburg site, and Marie-Christine John, my wife Hélène and my daughters Emmanuelle and Amélie for their translation of German and Russian texts. I also express my gratitude to Peter Eeckhout, Mathilde Gelin, and John Papadopoulos for their answers to my questions about their experiments. I thank Leah McCurdy and Elliot Abrams very much for inviting me to contribute a chapter to this volume as well as for their invaluable comments, along with an anonymous reviewer, on earlier drafts of this chapter.

Notes

1 This is an abstract of a thesis under the guidance of Stéphane Verger (EPHE Paris) published in 2019 (in French).
2 The fortification was 750 m long and 6 to 7 m high.
3 The average between two or three values is often used, in the absence of assessment criteria, to choose one of these values. The only advantage when using an average is to minimize the difference between this average and the most likely value. But if the values are far apart from each other, it is likely due to different experiment conditions. Then the average is not more justified; it is better to find why the values are dispersed.
4 Korobeinikov (2005) used a similar approach for earth digging values and referred to a nineteenth-century building manual. In Devolder (2013), the author was looking for the opposite goal: to define a standard cost for each task.
5 Supervision time is not often considered in energetics studies, even for large jobs. It may come from three facts: (1) authors often calculate only the direct labor force; (2) labor cost values are very often derived from experiments with few workers, so without supervision; (3) authors do not know how the jobs were organized. However, it is unthinkable that a large job with dozens of workers should not have been managed at least by a supervisor and foremen, and the quality of the supervision strongly influences the construction time performance. There is precedent to quantify the supervision time using values from 5% (Fathy 1989) to 10% (DeLaine 1997; Seeher 2007). I use 10% in my calculations and I consider that this must be a part of the labor cost, even if it is a "hidden" part.

6 L = lead, H = hours worked, q = quantity of earth per load, Q = daily output, V = velocity (loaded), V' = velocity (unloaded), c = loading time, d = unloading time, e = idle time.
7 Note that mere knowledge of the average speed of the round trip (which is not exactly the average between the velocities to and fro) is sufficient. The formula can then be written as: $Q = H/q \times 1/(2L/Va + c + d + e)$. Va being the average velocity.
8 Time values c, d, and e are not negligible when $L < 50$ m.
9 These values are not explicitly mentioned either in ECAFE or in the related UN document (1961). If interpreted, the values derived from the experiments mentioned in ECAFE would be q = 50 kg and Va = 4.5 km/h.
10 See for instance: 22 kg by Abrams (1984), Bernardini (2004), and Murakami (2009), 30 kg by Clark (1998), 40 kg by Devolder (2013), 44 kg by Lekson (1984) and Nelson (1995). The use of Aaberg and Bonsignore's values is surprising. As far as we know, no user of these values has ever called into question the non-justified values of V and V', and no user has ever varied these values according to the considered load.
11 Gersbach suggests a one month drying period, and mentions that for the construction of the "Bio-Hauser" at Tübingen, smaller mudbricks than those of the Heuneburg had to dry for two months (Gersbach 1995, 38).
12 The posts' number and locations have not been verified by a structural calculation.
13 0.6 is the average value for large projects. 0.44 is the chosen value for the Heuneburg mudbrick manufacturing time (stages 2 to 5). 0.30 is the value including stage 1 – raw material procurement – and the workshop construction – see Table 6.3.
14 The "Other Indians" transported on average 31 kg loads for 5.3 hours at these velocities in hot conditions. However, these workers were highly trained. We assume that the reduced training of our observed workers is offset by a lower load and a cooler climate.
15 The average speed is 3.66 km/h. In one day, a person walks $3{,}660 \times 5.33 = 19{,}509$ m, that is 30.5 leads of 640 m per day.
16 Total transportation time = 8,500/30.5/0.0148 = 17,843 p-d.
17 The diameter of the Hohmichele is 84 m. "O" is the center of gravity of the mound (modeling the mound as a truncated cone). "G" is the center of gravity of the excavated area. Velocity values derive from the International Labour Office (1963) report.

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5 To house and defend

The application of architectural energetics to southeast Archaic Greek Sicily[1]

Jerrad Lancaster

Introduction

In 733 BCE, a group of colonists from Corinth, located on the Peloponnese of modern Greece, landed in southeast Sicily at the island of Ortygia and formed the settlement of Syracuse (Thuc. 6.3.2).[2] This would become the first step of a hegemonic expansion across the southeast corner of the island, lasting over a century and establishing four Syracusan colonies and other smaller sites (see Figure 5.1). This process ended with the settlement of Kamarina on the southern coast in 599 BCE. Kamarina was established as an independent settlement (Thuc. 6.5.3), but was most likely intended to be dependent to a degree on Syracuse (De Angelis 2000a, 124).

Recent historiography of the region focuses broadly on the motivations (conquest, commerce, sociopolitics) behind the actions of Syracuse in the Archaic period (750–480 BCE), largely ignoring smaller aspects of colonial foundation and the interaction between Syracuse and its colonies. As an alternative or complement to this broad approach, examining certain features of the colonial process can lend insight into other macro-level factors present in the history of the area. Discussed here are two aspects of establishing a settlement: housing a population and constructing a defensive structure.

With regards to housing, in the initial days after foundation, the community at Syracuse would have been busy establishing the most integral aspects of a society: infrastructure, city planning, government. During this time, the settlers would have likely erected temporary housing while prioritizing the other projects. Through calculating the labor costs and population, the transition to permanent shelter is viewed quantitatively. New ideas are then brought forth on how this project may have been implemented, its importance in the entire colonial project, and when these structures may have been built.

In the mid-sixth century, the settlement at Kamarina was less than a half century old. By this time, however, it had established itself as a notable port on the southern coast of Sicily and within the trade routes of the region. Historical literature mentions, albeit briefly, how the colony was to be

Figure 5.1 Southeast Sicily in the Archaic period (after De Angelis 2016). Drawn by Leah McCurdy

independent, with its own *oikists* (founders), but Syracuse wanted to maintain some control (Thuc. 6.3.2). This resulted in a rebellion by Kamarina and its destruction at the hands of Syracuse in 552 BCE. Before this, the community at Kamarina constructed fortifications in an ill-fated attempt at defense. Projects of this magnitude involve large amounts of human and material resources, a major undertaking for a society. Archaeological remains of the walls here, however, paint a different picture. Examination of the construction costs and local populations detail the community's effort, perhaps their last, in a fight for survival and to exhibit their independence.

The city of Syracuse has been continually occupied for almost three millennia. For obvious reasons then, archaeological evidence of its initial settlement period has largely been lost. A similar circumstance exists at Kamarina, but for a more tumultuous reason. The settlement was destroyed on three separate occasions before its final destruction in 258 BCE by the Romans (Martin et al. 1980, 509). In between, the site was consistently resettled, altering the landscape and further destroying any remnants of the Archaic period. The application here of architectural energetics allows for the most distant history of each site to be reexamined through what evidence remains, shedding new light on the actions of these communities.

Methodology

The methodological application of architectural energetics used herein obviously follows that explained by Abrams and McCurdy (Chapter 1). The approach here differs in the use of a combination of literary and archaeological evidence of the time period and region, supplemented by applicable ethnographic studies. Columella's *Res Rustica* and Vitruvius' *The Ten*

Books on Architecture provide some insight into agricultural and construction activities, respectively, although these often omit specific details and require careful study (White 1965). Epigraphic records of contemporary construction projects, such as that at Classical Athens (Randall 1953; Stanier 1953; Burford 1963) and Epidauros (Burford 1969) also prove valuable. These studies, however, are often given in monetary value, and it is generally accepted that the economies of Sicily were largely non-numismatic in the Archaic period (Hill 1903, 36–37; Jenkins 1976, 8). When this is the case, day-wages and material costs must be converted to person-days.[3] Modern ethnographic investigations and experimental archaeology provide additional information where ancient sources are lacking (DeLaine 1997; Wright 2005). These must also be carefully studied, as these approaches can be problematic in finding direct, or proximate, correlation with modern and historical processes.

There are three essential assumptions taken into consideration when estimating labor costs during the Archaic period. First, the labor supply was made up of men.[4] This is a reasonable assumption based on the physically demanding nature of construction (DeLaine 1997, 106). This does not preclude the involvement of women or even young adults, but cultural tradition dictates that the strenuous manual labor would have largely been undertaken by men. In addition, this follows the normal practice of architectural energetics in providing minimum cost estimates. No distinction is made between freeborn and slave labor, as the legal status of a workman is unlikely to have affected his potential output.

Second, the length of the average working day is estimated at 12 hours, including 2 hours of breaks, and the typical year at around 220 days (DeLaine 1997, 105–106; Fitzjohn 2013, 638; Pakkanen 2013, 56). These take into account seasonably acceptable weather and presuming all daylight hours were used. Third, comparisons can be made between the average output of a laborer in the Archaic period and any later period up to the twentieth century as manual labor, the tools and their use have not diverged much in the past two millennia (DeLaine 1997, 105). In addition, dietary habits of ancient societies would not have proved to be any less beneficial towards productivity than in later periods.

Labor rates utilized in this study focus on the most important materials used in construction: stone, mudbrick, and wood. They are taken from the most applicable source, with preference towards the time period, region, and culture most aligned with the current study (Lancaster 2017, 58–81). Econometric calculations below follow the minimum estimates, but a range of costs is given in the accompanying tables. Both the lowest and highest labor rates for each construction process are given in Table 5.4; however, the calculations leading to the highest estimate are not provided, focusing on the minimum estimated costs.

Transport costs are based on the average distance a pair of oxen could travel in a day: 8 km, or 4 km each way (Pakkanen 2013, 70, n.131), given

in ox-carriage days (od). This is assuming travel on a fairly flat surface. Any changes in incline are accounted for through $P = mg\sin\theta$ where m is the mass of the load, g gravity and θ the angle of the slope, and the increase is directly proportional to the angle. This additional transport cost is only considered for Kamarina, as the geography of the island of Ortygia, and the nearby mainland, is relatively level. It will be seen that many of the estimated transport costs could be combined to lower their overall impact. This is not accounted for in the calculations below as such a practice would depend wholly on the organization of the project by the communities, an aspect that is unknown. Distances listed herein have been measured using Google Maps Distance Calculator (Daft Logic 2014).

Population estimates are calculated through an amalgam of recent demographic and landscape studies (Lancaster 2017, 82–91). A percentage of these estimates constitutes the available labor pool for construction projects. These workers, however, cannot be considered full-time laborers, and so other duties, most notably agriculture, must be accounted for to allot a practical amount of time able to be devoted to construction. Once calculated, the annual availability of person-days (p-d) leads to an estimated time line in which each project could be completed. The result is analyzed for its impact on the society and place within the history of the settlement.

Through assessing each facet of the project, the individual aspects are highlighted and the complexity of it is realized. The organization of human and material resources was important to allow for the various tasks to run simultaneously and smoothly. Then, evaluating the total labor costs and the length of time to completion provide a macro-level analysis of the econometric process, allowing for the construction projects to be viewed more fully not only as historical remains but as an act by the community.

Syracuse: Archaic housing

Upon arriving in Sicily, the colonists from Corinth settled on the island of Ortygia. The island is only about 50 ha in size, and likely did not provide much for material resources beyond timber. However, since the degree of forestation in the Archaic period is unknown for this area, a distance of 1 km will be taken as the length of transport for the procurement of timber. The Epipoli plateau, 2 km away on the mainland, is the closest known source for limestone. The river Anapo (ancient Anapos) is the closest freshwater source for mudbrick and clay, approximately 3 km from the center of the island. Diodorus Siculus (13.113.1) mentions how the Syracusans utilized reeds from the swamps on the mainland. This will be disregarded as minimal to the overall costs and as the material could have simply been gathered during transport.

Archaeological evidence is scarce for the foundation period housing, and even then, what is known is incomplete at best. The best preserved example is of a single room measuring 3.50 m on all sides, with walls 0.50 m in

width (Martin et al. 1980, 666; Pelagatti 1982, 126–129). Comparanda can be found nearby at Megara Hyblaia (Vallet et al. 1976, 268–269; cf. Gras and Tréziny 2004, 465–466), settled less than a decade after Syracuse. There the walls of the early houses were 4.50 m on each side and on average 0.45 m thick. An absence of mudbrick at both locations suggests they were built entirely of stone; however, given the cost efficiency of using mudbrick, such a construction technique cannot be dismissed (De Angelis 2016, 84). Therefore, labor costs will be derived for a house built both entirely of stone and with the use of mudbrick. The roofing structures are assumed to have been constructed without the use of tile, rather using organic material and at a slight incline to prevent water from accumulating (Vallet et al. 1976, 255–256; Gras et al. 2004, 459). Calculations will be based on a flat roof as the overall costs would not be much greater and this form is the simplest to reconstruct. Further, the most complete floor plan found at Syracuse will be reconstructed (see Figure 5.2).

Leveling the ground to a foundation depth of 0.25 m, including a 1 m gap for the doorway, removes 1.38 m^3 of earth at a cost of 0.19 p-d.[5] This earth then needs to be taken away from the construction site. In the initial stages of establishing a settlement, it can be reasonably assumed that it was reused elsewhere. A distance of 250 m will be used, as it is also the average distance from the center of the island to the coast. This process is completed in less than a single person-day and ox-carriage day.[6]

The height of the walls is unknown for obvious reasons. A comparative source for this can be found at Zagora, where a fully intact wall was discovered rising to around 2.50 m, with a doorway at 2 m (Cambitoglou and Coulton 1988, 149–150; Morris 1998, 22). Comprising the majority of the area above the doorway are the lintels and part of the roofing structure, and as this is the case, the remaining area to be completed in stone will be disregarded. Again, this minimally impacts the final calculations and provides

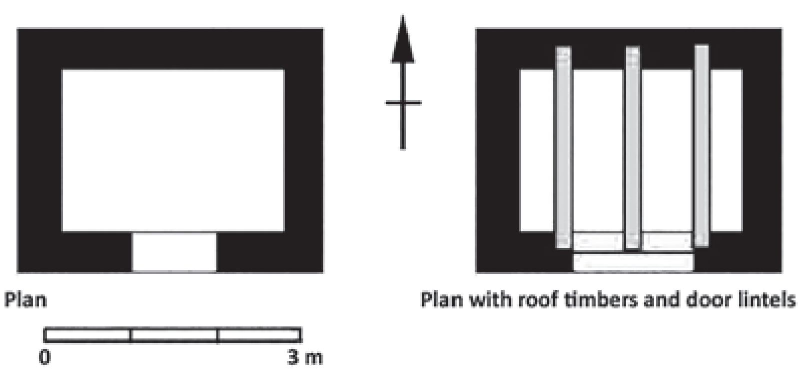

Figure 5.2 Syracuse House plans used in the econometric calculations. Drawn by author

the most basic reconstruction. With foundation depths of 0.25 m, the walls rose 2.25 m above ground level. Doorway openings were 1.75 m above ground level. This doorway height coincides with that found at Zagora. Each roofing beam is estimated to be 0.25 m in diameter, as are the lintels above the doorway. Each lintel is also calculated at 1.50 m in length, extending 0.25 m to each side of the doorway, negligibly lowering the stone amount within the context of the entire construction.

A house of these specifications incorporates 14.38 m³ of stone.[7] Quarrying, transporting, and constructing the stone walls is estimated at 18 p-d and 21 od.[8]

The flat roof is reconstructed here of three beams running from the entrance wall across to the opposite side, with no secondary supports. These beams likely remained rounded, placed 0.25 m into each end wall, or 3 m in length each. For equal spacing, the timber is estimated at 0.35 m in diameter and placed 0.48 m apart. The two door lintels are squared, 0.25 m by 0.25 m and 1.50 m in length. In total, this amounts to 1.29 m³ of timber, requiring 3 p-d for felling, 1 od for transport, and 1 p-d to square the lintels and set the structure in place.[9] In addition, organic material, such as earth, reeds, and clay would have been fastened over the roof to allow for weatherproofing and a flat finish. This is considered feasible in a single day.

The final step comes in the construction of the door. This can reasonably be sized at 1 m in width, 0.05 m thick, and 1.75 m high. Half a timber 0.33 m in diameter, cut into three planks, is sufficient. With squaring the timber, this process entails half a person-day and 1 od.[10] In total, including supervision costs, the construction of an all-stone house is estimated here at 27 p-d and 24 od, with the highest estimate at 76 p-d (see Table 5.1).

A house of the same dimensions and built primarily with mudbrick differs only in the construction of the walls. Mudbrick is placed atop a stone socle for the primary purpose of keeping the mudbrick off the moist ground (Fagerström 1988, 99). That estimated here assumes a socle 0.50 m high, completed in 4 p-d and 4 od.[11] Mudbrick gathered, manufactured, and transported from the river Anapo adds 8 p-d and 17 od.[12] With the roofing

Table 5.1 Total labor costs for the construction of an all-stone house at Syracuse

Resource	*Acquisition (p-d)*	*Transport (od)*	*Construction (p-d)*
Stone:	3.60	21	14.38
Initial Levelling of Site:			0.19
Disposal of Rubble:		0.53 p-d + 1	
Roof:	3.48	1	1.92
Door:	0.27	1	0.24
Totals:	7.35	0.53	16.73
Supervision:	0.74	0.05	1.67
Base Total:	27.07 p-d + 24 od		
Range of Totals:	27.07–76.45		

Table 5.2 Total labor costs for the construction of a mudbrick house at Syracuse

Resource	*Acquisition (p-d)*	*Transport (od)*	*Construction (p-d)*
Stone:	0.72	4	2.88
Mudbrick	2.88	17	4.60
Initial Levelling of Site:			0.19
Disposal of Rubble:		0.53 p-d + 1	
Roof:	3.48	1 od	1.92
Door:	0.27	1 od	0.24
Totals:	7.35	0.53	9.83
Supervision:	0.74	0.05	0.98
Base Total:	19.48 p-d + 24 od		
Range of Totals:	19.48–41.74		

structure and door, the total cost for a mudbrick house is 19 p-d and 24 od, with a high estimate of 42 p-d (see Table 5.2).

Immediately comparable is the cost estimate of Fitzjohn (2013, 631–635, see Table 2) for House 23,10 at Megara Hyblaia, measuring 4.50 by 4.50 m with a wall thickness of only 0.45 m. His total is quite a lot higher at 100 person-days, stemming from the rates he chose to employ. However, the implication from his approach, and here as well, is that these structures were unlikely to have been built individually with a single laborer. In comparing the all-stone with mudbrick alternative, the minimum cost difference is only a week's worth of labor for a single man, while the higher estimates differ by 35 p-d. Overall this is not a large disparity in so much as the construction of residential housing can be expected to have been underway at multiple locations simultaneously. Therefore, these processes would not only have been implemented by many laborers, but costs would be lower as material for many structures, possibly at various stages of completion, would have been gathered at the same time. One implication for the lack of mudbrick found in archaeological contexts at either Syracuse or Megara Hyblaia is that limestone may have been more readily available than is currently believed. However, given the labor cost comparisons, it may be more likely that the increase in cost, mitigated by the labor pool, was negligible in the desire to build more permanent housing.

Kamarina: the Archaic wall

The settlement of Kamarina is located on the southern coast of Sicily between the mouths of the rivers Ippari (ancient Hypparis) and Rifriscolaro (ancient Oanis). Dating has suggested that the wall was constructed hastily around the mid-sixth century (Frederiksen 2011, 154), which correlates strongly with the rebellion of Kamarina against Syracuse (553 BCE) and its

destruction. Therefore, because of the short time period in which it was built, stone was likely gathered locally within 0.50 km, not quarried as would be expected. For this reason, no added transport cost will be calculated for any change in elevation. On the other hand, the nearest source for mudbrick is the river Ippari, about 250 m on average from the different spans of the wall. For this the incline is a little over 4%, adding 7.5% to the transport costs.

The best available evidence of the fortifications comes from a 6-m-long section excavated in 1896 (Orsi 1899, 209–210). The wall was likely built with a stone socle upon which was placed a mudbrick superstructure. The socle width varied up to 2.60 m and consisted of a double curtain with an infill of rocks and earth. It is expected that the fortifications created a circuit around the entire early inhabitation area, c. 7 km in distance, with gates in three different locations. No archaeological evidence has been recorded of the gates, and so they will be disregarded here. Overall the fortifications are considered poorly constructed, likely due to the hastiness (Orsi 1899, 209–210), and similar in technique to Mycenean construction. Based on the minimum average height of contemporary walls (Frederiksen 2011, 95), they here will be reconstructed 4 m high, equal parts stone socle and mudbrick superstructure. While a taller wall cannot be dismissed, a wall this high would have been adequate, and the extra height may not have provided enough additional protection compared to the costs associated with doubling the materials.

Leveling the foundation down to a depth of 1 m necessitates the removal of 18,200 m³ of earth at a cost of 2,500 p-d.[13] This quantity will be set aside for later reuse as infill in the socle. A reasonable approximation of 2:1 is taken for the ratio of limestone to infill, calculated to 24,388 m³ of stone and 12,012 m³ of rubble.[14] Although it is not uncommon for walls to be built deeper into the interior or tapered inward above the foundation (Frederiksen 2011, 57), these possibilities will not be explored here. Costs for gathering, transport, and construction of the stone equal 73,200 p-d and 8,800 od.[15] Placing the rubble infill into the socle adds 840 p-d.[16] The excess rubble must then be taken elsewhere for disposal, and a distance of 250 m will suffice with no added cost for elevation change: 2,400 p-d and 1,100 od in total cost.[17] The superstructure is estimated at the same dimensions as the entire socle. This amount of mudbrick equates to a total of 23,700 p-d and 4,800 od.[18]

In total the fortifications at Kamarina are estimated at 113,000–293,000 p-d and 14,700 od (see Table 5.3). Even with the expectation that this was completed rather hastily under the looming threat from Syracuse, this was quite an extensive process. Therefore, to complete this endeavor quickly a large workforce must have been assembled, likely including those within the rural limits of the settlement. To what extent this was the case, answers may be found in population estimates, workforce size, and labor availability. This is discussed in the next section.

Table 5.3 Total labor costs for the construction of fortifications at Kamarina

Resource	*Acquisition (p-d)*	*Transport (od)*	*Construction (p-d)*
Stone:	24,388	8,807	48,776
Mudbrick:	9,100	4,756	14,560
Loosefill:	*Gathered during levelling*		841
Initial Levelling of Site:			2,548
Disposal of Rubble:		2,389 p-d + 1,117	
Totals:	33,488	2,389	66,725
Supervision:	3,349	239	6,673
Base Total:	112,863 p-d + 14,680 od		
Range of Totals:	112,863–293,084		

Population estimates

With the labor costs calculated, population figures, from which workforce sizes and time lines can be estimated, provide a way to analyze the impact the construction projects had on each settlement. Estimates given here are largely derived from previous studies by Muggia and Hansen (Lancaster 2017, 125–135). These surveys approach the topic from opposite angles. Muggia's study (1997) relies on the view that intramural open space was used as housing and/or agricultural land in times of emergency, while Hansen (2006), based on landscape studies and the physical remains of walled city-states, deduces population sizes through average rural settlement densities and percentages of the intramural habitation area.[19] Comparison issues with these studies arise as they are not uniform across all time periods and rely on suppositional comparanda where information is lacking. However, these studies are the most site-specific for the settlements discussed here. The most recent population estimates for southeast Sicily come from De Angelis (2016, 142–144), following Hansen's approach, although some discrepancies exist (Lancaster 2017, 87), and therefore his figures will be disregarded.

Syracuse

Estimated here is the urban population of Syracuse upon its foundation in 733 BCE. Current estimates for the end of the Archaic period (485 BCE) include Hansen's at 9,000–12,000 and Muggia's higher at 20,000. These estimates produce a range of 9,000–20,000 for the end of the Archaic period. De Angelis estimates an annual growth rate for Sicilian Greek settlements at 0.50%, however working backward at this rate leads to an unrealistically high range of 2,600–5,800 people for the foundation period. Therefore, I take a different approach, considering the total area of the island of Ortygia (50 ha), an expected inhabitation area of 20% to 100% from Hansen and

Muggia respectively, and a population density of nine people per hectare. This latter figure is estimated by De Angelis for Megara Hyblaia at its foundation (728 BCE) (De Angelis 2003, 44, see Figure 24). The initial population of Syracuse then drops to a range of 90–450 people. Through population modeling (Lancaster 2017, 127–128), the rise in population from 90–450 to 9,000–20,000 over the Archaic period approximates to a 1.5% to 1.9% annual rate of increase. This would include the growth rate of 0.50% with an inflow of 18–38 people (around four or five families) annually. This becomes essential in estimating the amount of time it took to house the entire community in permanent structures, which includes any new families arriving on the island.

Kamarina

Population estimates will be taken from 552 BCE, the date of Kamarina's destruction at the hands of Syracuse. Construction of the fortifications at Kamarina could have begun upon foundation in 599 BCE as walls were not uncommon in Greek settlements by this time. However, Kasmenai may have been the only settlement in the region with fortifications by the sixth century BCE, and that dating is uncertain. Further, historical accounts of the area do not suggest the settlement would have been under any imminent danger at that time. Fortifications, therefore, cannot be expected to have been a priority in the establishment of the city-state. Instead, it becomes more probable that the community began to defend itself as the conflict with Syracuse grew. In fact, as the archaeological evidence suggests, the construction was quick, using material only found in the immediate vicinity. With Kamarina initiating hostilities by crossing the river Irminio (ancient Herminius) (Dion. Hal. *Pomp.* 5.4), a construction date closer to 552 BCE is more plausible.

The tumultuous history of Kamarina makes population estimates more difficult. Not much evidence remains to estimate population size, and so comparisons must be made with the rest of the Greek world. As stated above, it is expected that the fortifications stretched c. 7 km in distance, creating a circuit enclosing an area of around 150 hectares. In her study, Muggia (1997) estimates that 48% of the intramural area was inhabited, although she does not provide a population figure for the period. Hansen (2006) uses Muggia's habitation density in his urban population estimate of 10,800–14,400 for the settlement in 552 BCE.

The number of inhabitants, both indigenous and Greek, within the hinterland of Kamarina is equally uncertain (cf. Di Stefano 2009). Generally, the area has been defined by the river Dirillo (ancient Achates) in the northwest, the Irminio in the southeast, and the highest reaches of the river Tellaro (ancient Heloros) in the Hyblaian Mountains to the northeast. This roughly covers an area of 670 km^2 (Muggia 1997, 97; De Angelis 2000a, 124–126; De Angelis 2000b, 112–113). However, based on a 15-km or 3-hour walking radius (Bintliff 2002), I have estimated the hinterland

attached to Kamarina at c. 650 km². The Dirillo and Irminio remain as boundary markers, but the eastern extent finishes near the modern city of Ragusa. Muggia expects a high settlement density in this area (four sites/km²) in the Classical period, but this is highly unlikely for the first half of the sixth century BCE. Instead, the estimate here will follow Hansen's study where the rural population comprises two-thirds of the total population: 21,600–28,800; roughly two to three sites/km².

Workforce size and labor constraints

With the labor cost calculations and population estimates, approximate time lines can be determined to gauge the impact of these construction projects on each settlement. Alas, this is not so straightforward. Only a small percentage of the community can be expected to have been able to participate in hard, manual labor. It has been suggested by Beloch that a proper workforce was about a quarter of the population based on able-bodied men between the ages of 20 and 60 (Beloch 1886, 42, 53). Hansen lowers the age range to 20–49, and excludes up to 25% of all adult males as unfit or indispensable (Hansen 2011, 241). Abrams estimates anywhere between 20% and 33% based on whether adult females or sub-adult males are included (Abrams 1987, 493). Most recently, De Angelis (2016, 146) employs Beloch's percentage but suggests that the upper-class citizens comprised around 10% of the population and likely did not participate in manual labor. Following this, 22.5% of the population will be taken as the size of the workforce.

A further constraint to any construction project comes in the agricultural calendar (Halstead 1987; Isager and Skydsgaard 1992, 160–162; Burford 1993, 120–143; Fitzjohn 2013, 627–629). Certain factors, such as the types of crops planted or the weather, became demanding to the members of the community engaged in agriculture at various times of the year, limiting their involvement in other tasks. In agrarian societies of Egypt and Central America, ethnographic studies suggest construction projects were confined to agricultural off-seasons (Abrams 1987, 490) 60–120 days a year. In New Guinea, this was lower at 40–45 days a year for communal projects (Erasmus 1965, 280). DeLaine's estimate of a 220-day working year does not account for agriculture, as the laborers were employed solely on the project, although she does admit weather and feriae likely disrupted working schedules (DeLaine 1997, 105). In addition, the oxen used to transport the material from source to site would have also been limited to when they were not needed in the fields. This "free time" was usually between July and September (Osborne 1987, 14–15; Salmon 2001, 200; Fitzjohn 2013, 631). Not enough is known about the agricultural economy of southeast Sicily to narrow down an exact calendar. Whereas grain was cultivated in abundance throughout Sicily (Gallo 1989; De Angelis 2006; Stika et al. 2008), animal husbandry and mariculture would also have been common, all needing attention throughout the year.

At Megara Hyblaia, Fitzjohn (2013) estimates that each house took at least a year to complete. His lowest estimate is 115 p-d, which implies that a single man had at most a third of the year to dedicate to construction. Given the constraints mentioned, a more reasonable expectation would be 10% to 25% of the year, or 1.2 (36 days) to 3 months (90 days).

A rural population has not been considered in the size of the workforce for Syracuse, although this does not eliminate those members of the community engaged in agricultural duties. Upon the founding of Syracuse, the fields in the immediate vicinity of the island of Ortygia would have been utilized for growing crops, and it can be expected that those occupied in farming the land would have commuted daily from the urban center. Consequently, these members of the urban population would have been limited in their construction involvement. Further, with other construction expectedly underway at this time (that is, infrastructure), the entire workforce would have been constrained by multiple projects. This also limits the amount of time available for building houses.

Population figures provide the estimated number of people in Syracuse upon its foundation and Kamarina in the mid-sixth century BCE. Historical and ethnographic studies limit the workforce size to just a percentage of the community, while placing further time constraints on availability due to the agricultural calendar. With these parameters, estimates can be calculated to the length of time it may have taken to provide permanent housing for the Syracusan settlers and fortifications around Kamarina.

Discussion

Estimates have been made of the number of laborers available for each project and the amount of days each year in which these men could have been free of other responsibilities to participate in construction. Multiplying these figures together provides a range of person-days per year allotted to each project. Given the total labor costs estimated for each project, approximate time lines then can be established. These can then lend insight into the relative impact of the project on the community and the society as a whole.

Upon the founding of Syracuse, the initial population of 90–450 would have required 23–113 houses, with a workforce of 20–100 men (720–9,000 p-d/year) to complete the project. A single all-stone house has been estimated at a cost of 27–76 p-d, and the mudbrick alternative at 19–42 p-d. For the all-stone house, if the workforce was only available 36 days a year (720–3,600 p-d), the project would have taken from one to three years to complete, accounting for the construction of additional houses as more families arrived in the settlement.[20] If available for three months of the year (1,800–9,000 p-d), the entire community could be provided permanent shelter in a few months to a year.[21] If building the houses with mudbrick, the timelines decrease to one to two years (at 36 days a year)[22] or half a year.[23]

Logically, each house would not have been worked on individually, and instead the labor force was pooled for certain parts of the project. For example, at a fifth of a person-day to dig a foundation, a single worker could complete five houses a day, meaning all the foundations could be completed in a single day. Transport costs can also be combined, lowering the reliance upon oxen. It is not unreasonable to think this project was completed in a year. In fact, if the community made permanent shelter a priority and employed the entire initial population, low-cost mudbrick housing could have been completed during the agricultural off-season. This is not entirely unfeasible, as some tasks such as dirt removal or mudbrick manufacture could easily have been accomplished by women and young adults. Indeed, this may have been the case as building permanent housing before winter may have been prioritized. Either way, it can be reasonably expected that the entire population was living within permanent housing within a year of their arrival. Once complete, it would only take a small crew to build more shelter as additional families arrived.

At Kamarina, the cost estimates of 112,900–293,100 p-d make it clear that constructing these fortifications was a major undertaking. However, with a total population of 32,400–43,100, the community must have felt it had the manpower, and this was indeed the case. A workforce of 7,300–9,700, potentially contributing 262,400–873,000 p-d a year, could have completed the project in a couple of months to a year.[24] In fact, if built in the summer, a rural workforce of 1,300–3,300 could have finished the fortifications in their off-season. This is quite plausible given the evidence of low-quality workmanship. The transport costs of 14,700 od may have been the biggest obstacle to overcome; yet if completed in the summer months, only 160 ox-carriages would have been required. Again, this is realistic as the hinterland would have had up to an estimated 1,900 farmsteads. Given that the material was gathered nearby, the costs could have been even lower.

At the end of the fifth century BCE, Dionysios I built the Epipolae fortifications on the northern flank of Syracuse (Diod. Sic. 14.18.2–8). This involved 60,000 people and 6,000 pairs of oxen, but with strong financial motivations it was completed in only 20 days (De Angelis 2016, 124–125). Comparisons are not direct in this case; the wall was only six km long but "of corresponding height" to Syracusan walls (ibid.). However, it does demonstrate clearly how quickly large-scale construction projects can be completed with proper motivation. With the rising threat of conflict against Syracuse, Kamarina may have wanted to demonstrate its independence by undergoing a major project without the help of its mother city. Alternatively, the community saw the inevitability of war and needed to defend itself. If the latter, completing this project, perhaps even in a few weeks, may have inspired the city-state to believe that it could survive without Syracuse. Unfortunately, such confidence may have verged on arrogance, as the events which followed Kamarina's crossing of the Irminio prove. In fact, one cannot be sure the fortifications were ever completed, as the defenses did not save the settlement.

The fortifications at Kamarina also highlight sociopolitical and cultural relations. Demonstrating that the community could complete such a project, presumably with the help of the local indigenous population, could have had ramifications related to power (Lang 2007, 185–186). Syracuse established settlements around southeast Sicily to control the area, its resources, and participate in regional trade (Lancaster 2017, 209–234). This was a strategy that took over a century to complete, with the founding of Kamarina at the beginning of the sixth century BCE. Kamarina was to be independent; it was too far away for direct governing by Syracuse. However, Syracuse still wanted the settlement to play its role in the region, and by building the fortifications, presumably without the permission of Syracuse, Kamarina's people made clear that they wanted, and indeed could survive with, independence. Further, having utilized the indigenous members of the community implies that relations between cultures were at least somewhat amicable (see Lancaster 2017, 46–48). This made obvious to Syracuse that the position of Kamarina in the settlement landscape had provided it with far too much power and capability. Syracuse may have even seen its colony as an eventual threat. All these issues would come to a head in 552 BCE with the destruction of Kamarina at the hands of its mother city.

Conclusion

The present study has demonstrated how architectural energetics can utilize multifaceted archaeological interpretation to reveal additional ways to understand past societies. Going beyond the basic facts of how a population

Table 5.4 Work rates used in architectural energetics calculations

Material	*Aspect*		*Base work rate (Cost)*	Highest rate
STONE:	Kamarina fortifications:	Quarry:	1 p-d/m³	2.5 p-d/m³
		Construction:	2 p-d/m³	0.11 p-d/m³
		Loose fill:	0.07 p-d/m³	
	Syracuse house:	Quarry:	0.25 p-d/m³	0.52 p-d/m³
		Construction:	1 p-d/m³	4 p-d/m³
	All:	Foundation:	0.14 p-d/m³	Shoring foundation (+ 10%)
		Load and carry 25 metres:	0.163 p-d/m³	0.18 p-d/m³
		Load into carriage:	0.06 p-d/m³	0.07 p-d/m³
MUDBRICK:		Manufacture:	0.25 p-d/m³	1.5 p-d/m³
		Construction:	0.4 p-d/m³	
WOOD:		Felling:	2.7 p-d/m³	5.39 p-d/m³
		Squaring:	0.14 p-d/m²	0.35 p-d/m³
		Roof timber:	0.1 p-d/timber	
SUPERVISION:		10% Added costs		25%
TRANSPORT:	Density of material:	Limestone:	2.6 tonnes/m³	2.9 tonnes/m³
		Clay:	1.75 tonnes/m³	
		Wood:	0.56 tonnes/m³	

was housed or chose to defend itself, practical interpretations of the decision-making process behind settlement planning allow us to grasp not just the results of the actions of the community but the actions themselves. This study offers a new perspective on the actions of people founding Syracuse and defending Kamarina to nuance the broad historical understanding of major events that shaped the sociopolitical landscape of the Archaic Mediterranean.

Acknowledgments

I would like to thank first and foremost Professor Jari Pakkanen for his supervision of the PhD thesis from which this study is derived. It took a lot of time and patience to introduce and fully explain the nuances of architectural energetics, especially to someone who entered this field in the hopes of avoiding math. To the PhD examiners, Dr. Tamar Hodos and Dr. Ellen Adams, who pushed me to bring out the most in my work, taking it to a level I never imagined. Dr. McCurdy and Dr. Abrams for allowing me to present my work in this volume. My colleague, mentor, and friend Dr. Michael Shott for the countless ways he has helped me in the beginning stages of my career. Most importantly, my family has been beyond supportive in my academic pursuits, helping me through all the obstacles, inside and outside of academia, that have led me to this point.

Notes

1 This chapter derives from an overall study on the settlement expansion of Syracuse in the Archaic period (Lancaster 2017).

2 A strong debate exists over the use of the term "colony" and its cognates in Classical scholarship (Lancaster 2017, 25–28 and references). While the term "settlement" is preferred here, colonial terminology has become a part of standard vocabulary on the topic and will be used here when appropriate.

3 For example, using average daily wages at Athens and the costs of different categories of building material, Pakkanen 2013 has estimated the construction costs in man-days for a typical Classical monumental, utilitarian building program.

4 The study from which this was taken (Lancaster 2017) implemented the use of man-days in the energetic calculations; however, to keep with the form of this volume, person-days is used here.

5 ((0.25 m × 0.50 m × 3.50 m) × 2 walls) + ((0.25 m × 0.50 m × 2.50 m) × 2 walls) – (0.25 × 0.50 × 1 m (doorway)) ≈ 1.38 m^3; 1.38 m^3 × 0.14 p-d/m^3 ≈ 0.19 p-d.

6 Loading and carrying + loading the cart + unloading and carrying: 0.163 p-d/m^3 + 0.06 p-d/m^3 + 0.163 p-d/m^3 = 0.386 p-d/m^3; 1.38 m^3 × 0.386 p-d/m^3 ≈ 0.53 p-d; 1.38 m^3 × 2.6 tonnes/m^3/0.9 tonnes per carriage-load ≈ 4 carriage-loads. (4 carriage-loads/16 trips per day) ≈ 0.25 od. Any figures less than 1 od will be rounded up.

7 ((2.50 m × 0.50 m × 3.50 m) × 2 walls) + ((2.50 m × 0.50 m × 2.50 m) × 1 wall) + ((2.50 m × 0.50 m × 1 m) × 2 front walls) = 14.38 m^3.

8 14.38 m^3 × 0.25 p-d/m^3 ≈ 3.60 p-d. 14.38 m^3 × 2.6 tonnes/m^3/0.9 tonnes per carriage-load ≈ 42 carriage-loads. (42 carriage-loads/2 trips per day) ≈ 21 od. 14.38 m^3 × 1 p-d/m^3 ≈ 14.38 p-d.

9 ((0.35 m × 0.35 m × 3 m) × 3 beams) + ((0.25 m × 0.25 m × 1.5 m) × 2 lintels) = 1.29 m^3; 1.29 m^3 × 2.70 p-d/m^3 ≈ 3.48 p-d; 1.29 m^3 × 0.56 tonne/m^3/0.9 tonne per carriage-load ≈ 1 carriage-load. (1 carriage-load/4 trips per day) ≈ 1 od; 4 (length-wise cuts) × 0.25 m (lintel width) × 1.5 m (lintel length) × 0.14 p-d/m^2 × 2 (lintels) ≈ 0.42 p-d; 5 timbers × 0.10 p-d/timber ≈ 0.50 p-d.

10 (1.75 m × 0.33 m × 0.33 m) × 0.5 (timbers) = 0.10 m^3; felling: 0.10 m^3 × 2.7 p-d/m^3 ≈ 0.27 p-d; transport: 0.10 m^3 × 0.56 tonne/m^3/0.9 tonne per carriage-load ≈ 1 carriage-load. (1 carriage-load/4 trips per day) ≈ 0.25 od; 6 (length-wise cuts) × 0.33 m (plank width) × 1.75 m (plank length) × 0.14 p-d/m^2 × 0.5 (timbers) ≈ 0.24 p-d.

11 ((0.50 m × 0.50 m × 3.50 m) × 2 walls) + ((0.50 m × 0.50 m × 2.50 m) × 1 wall) + ((0.50 m × 0.50 m × 1 m) × 2 front walls) = 2.88 m^3; 2.88 m^3 × 0.25 p-d/m^3 ≈ 0.72 p-d; 2.88 m^3 × 2.6 tonnes/m^3/0.9 tonnes per carriage-load ≈ 8 carriage-loads. (8 carriage-loads/2 trips per day) ≈ 4 od; construction: 2.88 m^3 × 1 p-d/m^3 ≈ 2.88 p-d.

12 ((2 m × 0.50 m × 3.50 m) × 2 walls) + ((2 m × 0.50 m × 2.50 m) × 1 wall) + ((2 m × 0.50 m × 1 m) × 2 front walls) ≈ 11.50 m^3; 11.50 m^3 × 0.25p-d/m^3 ≈ 2.88 p-d; 11.50 m^3 × 1.75 tonnes/m^3/0.9 tonnes per carriage-load ≈ 22 carriage-loads. (22 carriage-loads/1.33 trips per day) ≈ 17 od; 11.50 m^3 × 0.40 p-d/m^3 ≈ 4.60 p-d.

13 1 m × 2.6 m × 7,000 m ≈ 18,200 m^3; 18,200 m^3 × 0.14 p-d/m^3 ≈ 2,548 p-d.

14 (2 m × 2.6 m × 7,000 m) × 66% ≈ 24,388 m^3; (2 m × 2.6 m × 7,000 m) × 33% ≈ 12,012 m^3.

15 24,388 m^3 × 2 p-d/m^3 ≈ 24,388 p-d; 24,388 m^3 × 2.6 tonnes/m^3/0.9 tonnes per carriage-load ≈ 70,454 carriage-loads. (70,454 carriage-loads/8 trips per day) ≈ 8,807 od; 24,388 m^3 × 2 p-d/m^3 ≈ 48,776 p-d.

16 12,012 m^3 × 0.07 p-d/m^3 ≈ 841 p-d.

17 6,188 m^3 × 0.386 p-d/m^3 ≈ 2,389 p-d; 6,188 m^3 × 2.6 tonnes/m^3/0.9 tonnes per carriage-load ≈ 17,876 carriage-loads. (17,876 carriage-loads/16 trips per day) ≈ 1,117 od.

18 36,400 m^3 × 0.25 p-d/m^3 ≈ 9,100 p-d; 36,400 m^3 × 1.75 tonnes/m^3/0.9 tonnes per carriage-load ≈ 70,778 carriage-loads. (70,778 carriage-loads/16 trips per day) + 7.5% ≈ 4,756 od; 36,400 m^3 × 0.4 p-d/m^3 ≈ 14,560 p-d.

19 In 2008, Hansen updated his Shotgun Method (Hansen 2008) with more evidence leading to the conclusion that his estimates were low. This update does not largely affect the present study, more the overall image of the Greek world. For this reason and the sake of estimate ranges, I refer to the original study.

20 (23 houses × 27.07 p-d)/720 p-d/year ≈ 0.86 years; (((0.86 years × 4 families/year) + 23 houses) × 27.07 p-d)/720 p-d/year ≈ 0.99 years. (113 houses × 76.45 p-d)/3,600 p-d/year ≈ 2.40 years; (((2.40 years × 9 families/year) + 113 houses) × 76.45 p-d)/3,600 p-d/year ≈ 2.86 years.

21 (23 houses × 27.07 p-d)/1,800 p-d/year ≈ 0.35 years; (((0.35 years × 4 families/year) + 23 houses) × 27.07 p-d)/1,800 p-d/year ≈ 0.37 years. (113 houses × 76.45 p-d)/9,000 p-d/year ≈ 0.96 years; (((0.96 years × 9 families/year) + 113 houses) × 76.45 p-d)/9,000 p-d/year ≈ 1.03 years.

22 (23 houses × 19.48 p-d)/720 p-d/year ≈ 0.62 years; (((0.62 years × 4 families/year) + 23 houses) × 19.48 p-d)/720 p-d/year ≈ 0.69 years. (113 houses × 41.74 p-d)/3,600 p-d/year ≈ 1.31 years; (((1.31 years × 9 families/year) + 113 houses) × 41.74 p-d)/3,600 p-d/year ≈ 1.45 years.

23 (23 houses × 19.48 p-d)/1,800 p-d/year ≈ 0.25 years; (((0.25 years × 4 families/year) + 23 houses) × 19.48 p-d)/1,800 p-d/year ≈ 0.26 years. (113 houses × 41.74 p-d)/9,000 p-d/year ≈ 0.52 years; (((0.52 years × 9 families/year) + 113 houses) × 41.74 p-d)/9,000 p-d/year ≈ 0.55 years.

24 112,863 p-d/873,000 p-d/year ≈ 0.13 years. 293,084 p-d/262,440 p-d/year ≈ 1.12 years.

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6 Labor mobilization and medieval castle construction at Salemi, western Sicily

Michael J. Kolb, Scott Detrich Kirk, and William M. Balco

Introduction

When Arab and Berber invaders began their conquest of Sicily in 827, their intent was the strategic control of Mediterranean trade networks (Abulafia 2013; Davis-Secord 2010; Hodges 1982; Hodges and Whitehouse 1983; Kirk 2013; Molinari 2010; Wickham 2004, 2005, 2009). Control of the island was vitally important for economic and political consolidation. These new conquerors immediately began modifying existing fortifications and building new castles at locations across the island.

Roughly two centuries later, however, Arab castles proved insufficient in the face of the Norman invasion of 1072. Norman goals were to gain control of the island for Christendom and generate trade and agricultural wealth, resulting in a three-way power struggle between the Arabs, Normans, and Byzantines (Bachrach and Bachrach 2017, 266). Once the Normans solidified their control over the island, their goal was to construct a network of royal castles, here referred to as founding citadels (castles designed to take and keep control of large swaths of territory), that could be used in tandem to maintain control of the island. These worked in contrast to Arab fortifications which often served as independent refuges for local populations.

In the traditional sense, Norman-built fortifications were aligned with the motives and actions of self-aggrandizing elites seeking to retain and increase their social status and economic power (Hull 2006, 125–126). Historians and archaeologists can, therefore, use castles to envisage a hierarchical political landscape based upon the spatial variation in their number, size, and structural complexity (Fairclough 1992; Mathieu 2001). However, the primary measure of the power and authority of castles – the labor utilized to construct them – is implicitly accepted but not often satisfactorily quantified within a contextual framework of the societies that built and used them.

The goal of this chapter is to examine castle labor mobilization in order to identify changes in the medieval political economy of Sicily. We do so by calculating the labor invested in the western Sicilian castle of Salemi to

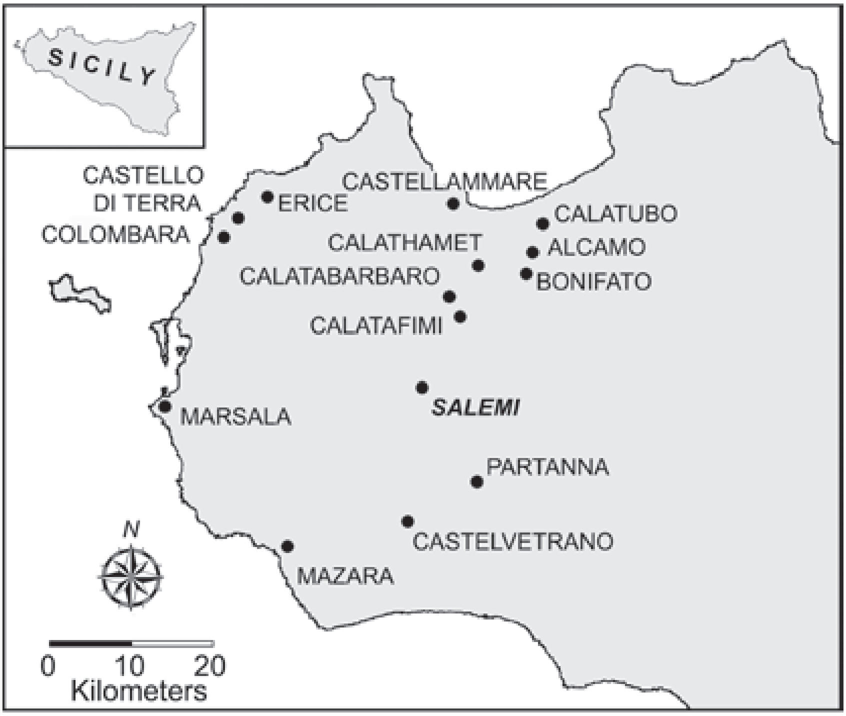

Figure 6.1 The location of Salemi and other relevant castles

address broad questions about the nature of labor mobilization for defensive and economic purposes (Figure 6.1). Our viewpoint is behaviorist (Abrams 1994; Kolb 1994; Moore 1996; Smil 2008; Trigger 1990), and we argue that castles are blunt expressions of supra-local social power that operated within the social context of medieval Sicily. The larger the castle, the greater the amount of energy and technology harnessed and controlled. Mobilized resources may certainly be dedicated to other archaeologically less conspicuous ends, but castle construction offers us a basic understanding of the magnitude of investment that, if conjoined with historical and contextual data, becomes particularly robust in terms of explanation.

We begin by providing a brief chronological and archaeological overview of medieval Sicily and continue with a discussion of the social dimensions of castle building in terms of architecture and labor costs. We then develop a model of Sicilian labor mobilization using fine-grained data on the construction of Salemi Castle in western Sicily. In conclusion, we explore how labor was differentially invested at other castles in western Sicily in order to examine political and economic change.

Background

For the past two decades, the meaning behind castles and the extent to which they were defensible has been a point of contention for researchers studying medieval Europe. While it is clear that castles were monumental displays of elite authority and wealth, the notion that they served as defensible bastions has been challenged by recent postmodern scholars (e.g. Askew 2016; Johnson 2010, 2002). They instead argue that many castles throughout Europe were not designed for, nor could they survive, a prolonged attack because either the design of the castle had major vulnerabilities or the castle can become a death trap for those confined inside it without adequate food or water (Creighton 2012). While this may be true at certain periods and locales during the later Middle Ages, these studies addressed Northern Europe – specifically England, France, and the Low Countries.

We argue that this was definitely not the case for Sicily prior to the sixteenth century. Indeed, the Norman conquerors of Sicily embodied a warrior elite class common across much of Europe since late antiquity (cf. Duby 2009; Brown 2013). As such, many of their castles could not be said to have been palatial in the same way that the later castles were (Purton 2010, 33). Most of them were incorporated into a network of Norman founding citadels, built at the center of hilltop settlements and using the rugged topography of the island to their advantage (Kirk 2016). While the goal of these, as well as later castles of the Swabians, was to project stately power (Bresc and Maurici 2009; Kirk 2016), they were also integrated into the defenses of a number of towns – such as Messina in eastern Sicily and others – that have been recorded as surviving sieges (Purton 2010). Thus, in many ways the founding citadels of the Normans were as functional as they were symbolic. To better understand the nature of castle construction and function in Sicily, we provide a brief political and architectural chronology (between the sixth and sixteenth centuries).

Byzantine Sicily (530–831)

While monumental forms of defense were prominent in many urban centers during the Roman period, the Eastern Empire did not spend as much on strengthening these foundations after the Byzantine conquest of Sicily in 535 (Maurici 1992). Though castle building was known throughout the Byzantine world, few castles can be securely dated to this time period in Sicily and it has been argued that by the time of the Islamic conquest, people were beginning to reoccupy older, fortified hilltop settlements dating to the Iron Age rather than fortifying low-lying, valley settlements inhabited during the Roman period.

Islamic Sicily (831–1061)

Arab incursions into Sicily were first undertaken for quick profit, but culminated with invasion and nearly a century of internal warfare (Metcalfe 2009;

Norwich 2015; Smith 1968). Unfortunately, while much is known about urban centers during this period, we know rather less about life in the smaller villages and countryside. Inferences can be made with the ephemeral remains of rural forts in Sicily and other parts of the Islamic world where fortifications known as *husun* (singular *hisn*) offered shelter to smaller settlements in time of crisis (Molinari 2010; Rotolo and Civantos 2013). Concurrently, in Christian Europe, castles built on hilltop locations assured elite control over surrounding trade routes and farmlands, providing safety for both laborers and travelers in a process known as *incastellamento* (also see Boone 2009, 19, 98; Boone and Benco 1999, 95–96; Glick 1995, 15; Metcalfe 2009, 57; Rotolo and Civantos 2013, 222, 242; Toubert 1973, 1990). These two phenomena, the hisn and the incastellamento fortresses, functioned differently and are difficult to compare.

Norman Period (1061–1194)

Under the early Norman rulers, Sicily became a place where the Arab east merged with Latin west; where Christian Norman, Muslim Arab, Orthodox Byzantine Greek, and Jewish communities coexisted. The Normans expanded their control into North Africa, participated in the crusades, and maintained economic ties with the rest of Europe (Abulafia 2013; Brownworth 2014; Norwich 2015). In Sicily, the Norman Period was a relatively peaceful time with Arabic-speaking Muslim communities surviving more than two centuries after the Norman conquest (Abulafia 2007, 2013; Metcalfe 2009; Norwich 2015; Smith 1968). Norman art and architecture expressed a unique cultural combination of Byzantine domes and mosaics, Latin arcaded loggias, and Arab arches, eight-pointed stars, and scripts all displayed in the same buildings.

During this time, castle building increased substantially for both Normans and those Muslim residents who wished to resist their rule (Kirk 2016; Metcalfe 2009; Molinari 1998). The Normans altered many of the Islamic husun into a more European style of castle as elites took up residence and built feudal or semi-feudal tenant-lord relationships with nearby communities. These new "founding citadels" symbolized both Christianized and centralized authority under the Normans that did not exist in the Islamic Period (Bresc and Maurici 2009), not altogether unlike the approach taken during the Norman conquest of England (cf. Mathieu 2001; Morris 2016).

The Swabian Period and the Sicilian Vespers (1194–1372)

The Norman Period ended with a primogenitary shift in rulership to the Hohenstaufen family of Swabia. The Sicilian people became highly Latinized during this period, and following a series of revolts, thousands of Muslims were exiled or converted (Abulafia 2013, 2007; Metcalfe 2009;

Norwich 2015; Smith 1968). A further struggle of investiture between the Norman/Swabian bloodlines and the Papacy resulted in the crown of Sicily eventually falling to the rather unpopular Charles of Anjou. Subsequent unrest across Sicily led to open rebellion in 1282 (known as the Sicilian Vespers) and resulted in the island falling under the control of the Aragonese Crown (Norwich 2015).

Architectural design gradually lost its Byzantine and Arab influence, but castle building nevertheless continued with most of the arched *bifora* (mullioned two-light windows; see Salzman 1979, 93) found in Sicilian castles dating to this period. During the period following the Sicilian Vespers, many local feudal lords and magnates constructed and occupied castles and towers in the absence of a strong centralized authority in Sicily (Abulafia 2013; Gomez 2007; Norwich 2015; Smith 1968; cf. Bachrach and Bachrach 2017, 260), focusing on elite investiture rather than popular defense (Kirk n.d.). This contrasts sharply with Norman rule where many of the island's castles were state owned enterprises (cf. Bresc and Maurici 2009; Kirk 2016).

Spanish Rule (1372–1713)

Until the fifteenth century, Sicily was ruled by members of the ruling house of Aragon as a semi-independent territory; it was formally inducted into the Kingdom of Aragon in 1409 and, later, the larger empire of Spain. Threats to the island at this time were largely seen as external rather than internal with historical sources noting the prevalence of piracy in the waters around Sicily and the Spanish conflict with the Ottoman Empire (Abulafia 2013; Epstein 1992; Kirk n.d.; Maurici 1985; Maurici et. al. 2008; Mazzarella and Zanca 1985; Smith 1968). Large castles were no longer built, and were replaced by a few larger military installations and a series of small towers constructed to protect the coastline.

Castle design and architectural elements

What we know about medieval castle construction is derived from a vast amount of architectural, military, and archaeological research on fortification design (Bachrach 1984; Bachrach and Bachrach 2017). Castles were multifunctional buildings designed for a wide array of societal needs. Primary amongst these needs was defense. As such, castles in Sicily and other parts of Europe were created as bounded spaces used to protect and defend political elites, communities, strategic locations, and/or economically important resources. In Sicily, these structures were often located upon promontories or coastlines, commanding a panoramic view of the surrounding area, to monitor and tax local activities (Kirk 2016).

While the design and modification of castles evolved over the centuries, we focus on five fundamental architectural elements that serve as basic building blocks of castle foundations: (1) placement; (2) materials; (3) foundations;

(4) walls; and (5) towers. Focusing upon these five elements allows for easy and uniform labor mobilization calculations.

Placement

Choosing the location of a castle was an important and complex decision, often dictated by the presence of existing settlements, cost of access to the building site, modified and/or natural terrain, as well as the transport distances for building materials such as stone, sand, and wood. High promontories were often selected as suitable locations for Sicilian castles because of their defensive characteristics, particularly prior to and during the Norman Period; however, such locations became less important for castle placement over time (Kirk 2016).

Materials

Practically any available material was utilized in castle construction. In Northern Europe, many of the earliest castles were made of wood (Creighton 2012; Salzman 1979, 264), and little is known about them as they have long since perished or been replaced by stone structures. However, in Sicily the primary building material for castles has always been stone because of short supplies of wood. Indeed, limestone has been the primary building material since antiquity (cf. Bachrach and Bachrach 2017, 258), and by the time of the Norman conquest, many Sicilian hilltop stone fortifications dated back not only to the Arab conquest but also to antiquity (see Kirk 2016; Tuzzolino et al. 2006).

Stone building materials consisted of extrusive rocks that were surface collected as well as cracked or cut rocks that were quarried from nearby outcrops. Limestones of different varieties were preferred because they could be easily shaped into blocks with metal or stone tools. Rocks were laid into walls and foundations with lime mortar serving as a structural cement. Often, many internal castle features such as flooring and stairways followed Roman Period techniques (Bachrach and Bachrach 2017, 254–245; Viollet-le-Duc 2005), and Roman ruins provided ample recyclable building materials (Hislop 2016, 96).

Foundations

The foundations of a castle, wherever possible, were often built directly onto underlying bedrock to prevent attackers from undermining the walls (Hislop 2016, 54; Salzman 1979, 83). This is in contrast to the motte and bailey castles of Norman England that would see the castle keep built on an artificial motte in the center of the complex. Indeed, many Sicilian castles (e.g. Calatubo, see Figure 6.1) were built directly onto rocky outcrops and employed extensively excavated or carved chambers in their designs.

In other cases, such as Salemi, promontories were leveled and wall trenches were dug to expose the bedrock. Wall stones were laid directly onto the bedrock and mortared in place to create the sturdiest possible foundation. If the bedrock was too deep or unsuitable, a foundation trench was excavated and then filled with packed stone rubble to create a solid footing for wall construction.

Walls

Medieval masonry practices were derived from Roman techniques (Hislop 2016, 58), and castle walls in the Norman period were usually exterior-faced stone blocks with rubble core-filled interiors (see Salzman 1979, 88). The exterior of all walls were not uniformly made of the nicest material and the crudely faced stones used on some buildings often bore remarkable similarities to the rubble core on the inside with the sole difference being that more sand and mortar were used in the core of the wall than on the outside.

Mortar was used to cement the stonework together with wooden frames holding the stone in place while the mortar dried. Wooden scaffolding was needed to construct walls that exceeded two or three m in height and horizontal beams were inserted into *putlog* holes built into the wall for this purpose (Salzman 1979, 316). Walls averaged 1.5 m thick, but could be as wide as 5 m when built to protect a central keep. These walls usually connected to a series of towers that provided better defense against attackers approaching from outside the castle.

Towers

Towers served as centralized keeps within the earliest castles and as bastions of defense within outer curtain walls throughout the Middle Ages. In much of Europe, keeps were usually freestanding, four-sided, or rounded stone buildings that afforded additional protection for defenders (see Toy 1985, 66–80). In the modern ruins of Sicilian castles, freestanding tower keeps are a rarity, but this may not have been the case during the Norman Period.

Castle keeps, whether freestanding or not, were traditionally the most strongly fortified point in a castle, and were usually buttressed with additional stonework. Built between two and four stories in height, most tower keeps averaged between roughly 25 and 35 m in height. Each interior floor was typically partitioned into rooms using walls of stone, wood, or sometimes simple canvas. Storage areas were usually located on lower floors and residential quarters for noble lords and other important persons were found on the upper floors.

Towers in outer castle walls served as important bastions that provided multiple angles of defensive fire against attackers who were funneled towards the walls or gate (Viollet-le-Duc 2005). They were often built higher than their connecting walls, providing additional safety and visibility for guards

and defenders. During the late eleventh century, the round tower was reintroduced as an intentional architectural design to better deflect the blows of battering rams and artillery (Bachrach and Bachrach 2017, 258).

Labor mobilization: Langeais castle

We begin our reconstruction of labor mobilization strategies by devising a descriptive model that isolates and details the basic principles of human labor activities; that is, quantifications of labor expenditures such as raw material acquisition, transportation, construction efforts, and the role of skilled laborers (e.g. Abrams 1987, 1994; Abrams and Bolland 1999; Kolb 1994). Examination of the scale of construction of public architectural features provides clues to their intended use and offers insight into the organization of the community that constructed them. The labor energy costs involved in architectural construction represent a common currency for measuring and comparing diachronic differences in organizational levels of production.

The labor estimate calculations we employ for western Sicily are based on the classic work of Bernard Bachrach who conducted field experiments at Langeais Tower in France (Bachrach 1984). He chose Langeais because: (1) its original dimensions and characteristics were largely intact; (2) a large corpus of historical documents regarding its construction from 992–94 was available; (3) ample literature regarding medieval building practices was available. Bachrach grouped his labor costs into: (1) material procurement costs (stone, mortar, and wood); (2) transportation costs; (3) construction (both skilled and unskilled) costs.

The material and energetic conversion rates Bachrach employed were derived from experimental, observational, and historical records of digging, quarrying, masonry, and woodworking activities at Langeais Tower (see Table 6.1). Here, procurement includes those costs associated with obtaining raw materials given in a measure of metric tons per cubic meters (t/m^3) and person-days per ton (p-d/t). Raw material costs include those for uncut stone core-fill, cut ashlar facing block, rubble, sand, and green wood for manufacturing mortar. Transportation costs for all materials are calculated at 0.3 person-days per metric ton per 1.6 km (p-d/t/km) of distance. Construction costs include digging, masonry, and non-specialized labor costs per cubic meter. Each cubic meter of walled stonework consists of 17% cut stones, 53% rubble fill, and 25% mortar.

A summary of the labor mobilization estimates for Langeais Tower is presented in Table 6.2. It includes detailed estimates of raw materials including 1,318 m^3 (3,058 t) of building materials. Bachrach estimates that the procurement, transport, and labor costs are approximately 94,000 person-days requiring a labor force of approximately 140 workers employed for 600 days (the average number of workdays per year is 300 [Salzman 1979, 44–62]). He further estimates that to sustain these workers would

Table 6.1 The material and energetic conversion factors derived from experimental, observational, and historical records for Langeais Tower (Bachrach 1985)

Procurement costs	*t/m³*	*p-d/t*	*Construction costs*	*p-d/m³*
Stone rubble	2.6	1.0	Digging foundation	0.25
Stone, cut ashlar	2.6	21.0	Laying foundation	0.4
Sand	1.6	0.3	Mixing mortar	0.1
Green wood for kiln	0.5	0.9	Masonry labor	10.6
Wood for milling	0.5	1.7	Smithing labor	1.3

Material transportation costs are 0.3 person-days (p-d) per metric ton per 1.6 km transported. Each m³ of stonework is comprised of 17% cut stone blocks, 53% rubble fill, and 25% mortar (a 3:1 ratio of crushed limestone to sand)

Table 6.2 Labor mobilization estimates for Langeais Tower, France (perimeter = 55 m, height = 16 m, wall thickness = 1.5 m, 1600 m², 1200 m³) as calculated by Bachrach (1984)

	m³	*Weight(t)*	*Procurement(p-d)*	*Transport (p-d)*	*Labor(p-d)*
STONE					
Facing stones	200	521	10,942		
Fill	700	1,742	810		
Mortar	300				30
Foundation	70	170			54
MORTAR					
Sand		141	45		
Wood		289	480		
Limestone		160			
Kiln use			1,500		
WOOD					
Planking	18	13	145		
Beams	30	22	63		20
Nails		0.05	17		15
LABOR					
Masonry labor					12,720
Common labor				2,015	63,500
Skilled labor					1,600
TOTAL MATERIALS	1,318	3,058	TOTAL PERSON-DAYS		93,956 [a]

[a] A typological error in Bachrach's summation tallies the total person-days as approximately 83,000 labor-days rather than what he actually calculates as 93,000 person-days.

have required an additional 460 agricultural workers cultivating 2,700 hectares of arable land, roughly about four to five agricultural workers per laborer. While such an expense may seem daunting, Bachrach points out that the economic reality of castle building was a very cost-effective military

strategy – considerably less than sustaining a similarly sized mounted force (a single mounted warrior required 12 agricultural workers for support).

While Bachrach takes great care in detailing his calculations, drawing certain inferences from labor estimates must be done with caution. Person-day calculations of durable stone features are simply relative figures; they do not take into account every discrete labor task involved in construction. For example, little is known about logistical support, and even less is known in regards to building perishable wooden features such as flooring and support scaffolding. Furthermore, interior ostentation (e.g. painted walls, sculptures, tapestries, furniture, etc.) would have likely taken additional labor that is not tallied here. What such calculations do represent are heuristic comparative values that shed light upon larger questions that address labor mobilization and the elite political forces that governed social spending.

Labor mobilization: Salemi Castle

Bachrach's labor calculations can be applied to the castle of Salemi, one of the "founding citadels" used by the Normans in western Sicily (see Figure 6.2).

Figure 6.2 A nineteenth-century image of Salemi and its castle as seen from the northwest (archives of the Biblioteca Comunale Simone Corelo, Salemi, TP)

Detailed labor estimates are possible for Salemi Castle based on data from our archaeological excavations (2004–10) in tandem with modern restoration efforts (see Itinera Lab 2010; Nuzzo n.d.) that provided us with construction details such as original wall foundation depths, thicknesses, and heights. Despite the present-day Salemi Castle being largely the product of a thirteenth century renovation (Caruso 1998; Maurici 1992; Militello and Santoro 2006), it has nevertheless been possible for us to tease out the early construction phases based upon architectural and archaeological analysis.

The labor estimates for Salemi Castle are presented in Table 6.3. Figure 6.3 visually juxtaposes its three building phases: (Phase I) a pre-thirteenth century Arab or Norman keep or tower; (Phase II) a Norman-Swabian expansion of the thirteenth century; (Phase III) the inner fortified room additions of the fourteenth century.

Phase I – Pre-thirteenth century

The spring-fed hilltop of Salemi was first favored by the indigenous Elymi during the sixth to fourth century BCE (cf. Balco and Kolb 2009; Kolb and Tusa 2001; Kolb et al. 2007), and later by first century BCE Roman landholders who exploited *latifundia* slave labor (Kolb 2007). Late Roman/Byzantine Period settlement was dispersed in the valleys below (Kolb and Vecchio 2003) particularly near the Basilica of San Miceli (Younker and Lesnes 2016). This basilica, and likely the surrounding village, seems to have been destroyed during the Arab conquest, prompting resettlement back up to the more easily defended hilltop and work on fortification efforts. Byzantine artifacts and possible castle elements dating to the Byzantine Period suggests limited Byzantine presence predating the medieval hilltop settlement. The presence of a Norman occupied castle at Salemi was first observed by the Arab geographer al-Idrīsī in the twelfth century (Idrisi 1967), most likely a reinforced keep or tower located on the southeast corner of the existing castle (Caruso 1998; Tuzzolino et al. 2006, 439–443). The existing tower probably bears little resemblance to its original form after it was renovated in the thirteenth century.

Castle courtyard excavations conducted in 2004 provide additional information regarding the construction and modification of the castle during its use (see Figure 6.4). Two Arab-Norman pits, likely bell-shaped cisterns or silos, were cut directly into the chalky bedrock and did not appear to be lined with any form of plaster or cement. The first pit was filled with refuse very quickly, as indicated by pottery refits across several strata. The second pit appears to have been intentionally filled with alternating layers of cracked stone and refuse. Pit features such as those identified in the castle courtyard were commonly used for grain storage during the twelfth and thirteenth centuries and similar features can be seen in both farmhouses and larger population centers, typically concentrated in areas designated for grain storage (Arcifa 2008). Many castles had similar features throughout

Table 6.3 Labor mobilization estimates given in person-days (p-d) for Salemi Castle, Sicily

Building	*Wall area*	*Volume*	*Weight*	*Procure*	*Transport*	*Construction*	*Total*
Element	*m^2*	*m^3*	*(t)*	*(p-d)*	*(p-d)*	*(p-d)*	*(p-d)*
PHASE I							
se tower	135	1,442	3,691	6,264	1,230	93,716	107,474
PHASE II							
n wall	76	910	2,397	3,981	799	59,154	67,914
nw (round) tower	113	2,289	5,680	9,871	1,893	148,746	170,382
west wall	53	638	1,683	2,794	561	41,517	47,666
sw tower	87	1,143	2,915	4,962	972	74,301	85,196
south wall	67	874	2,285	3,816	762	56,807	65,201
east wall	120	1,409	3,594	6,118	1,198	91,618	105,052
ne tower (estimated)	47	558	1,471	2,442	490	36,288	41,663
great hall	204	296	835	1,318	278	19,274	22,189
circuit wall	4,017	975	2,987	4,439	996	63,522	73,395
TOTAL	4,784	9,092	23,846	39,741	7,949	591,226	678,657
PHASE III							
sw room	91	733	1,876	3,184	625	47,632	54,624
se room	104	819	2,098	3,560	699	53,268	61,088
TOTAL	195	1,552	3,974	6,744	1,325	100,899	115,712
GRAND TOTAL	5,114	12,086	31,510	52,749	10,503	785,842	901,843

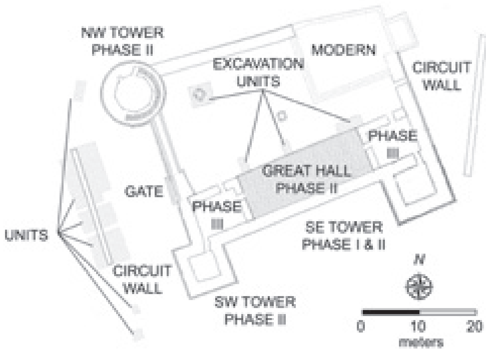

Figure 6.3 A plan view map of Salemi Castle that includes the building phase of its various architectural features as well as relevant 2004–10 excavation units

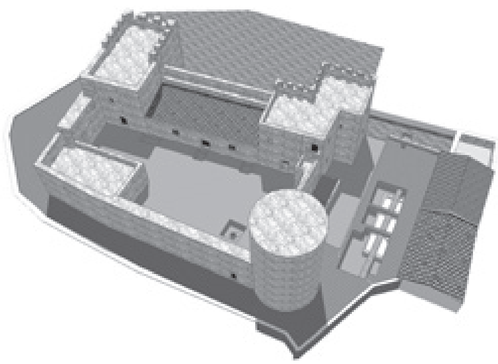

Figure 6.4 A three-dimensional reconstruction of Salemi Castle and its excavation units

the Mediterranean, such as the nearby Erice Castle (Cultrera 1935), attesting to the importance of medieval grain storage in secure locations.

The chronology of ceramic finds from these two pits date to the twelfth century and include simply decorated *scodelle* with black or green oblique bars painted along the rim (see Figure 6.5), a common form in western Sicily (Mangiaracina 2013). Fragments of yellowish-green glaze pottery were also recovered, firmly dated to the second half of the twelfth century, also common to western Sicily (Arcifa 1998; Lesnes 1998; Molinari 1995), providing a *terminus post quem* for the filling and abandonment of the pits.

Regarding labor investment, Phase I consists of the southeast tower and lower sections of the south wall that directly faced the public square of the medieval hilltop community. These elements contain unusually large facing stones (150 × 30 × 50 cm) stacked and dressed in a technique dating to the

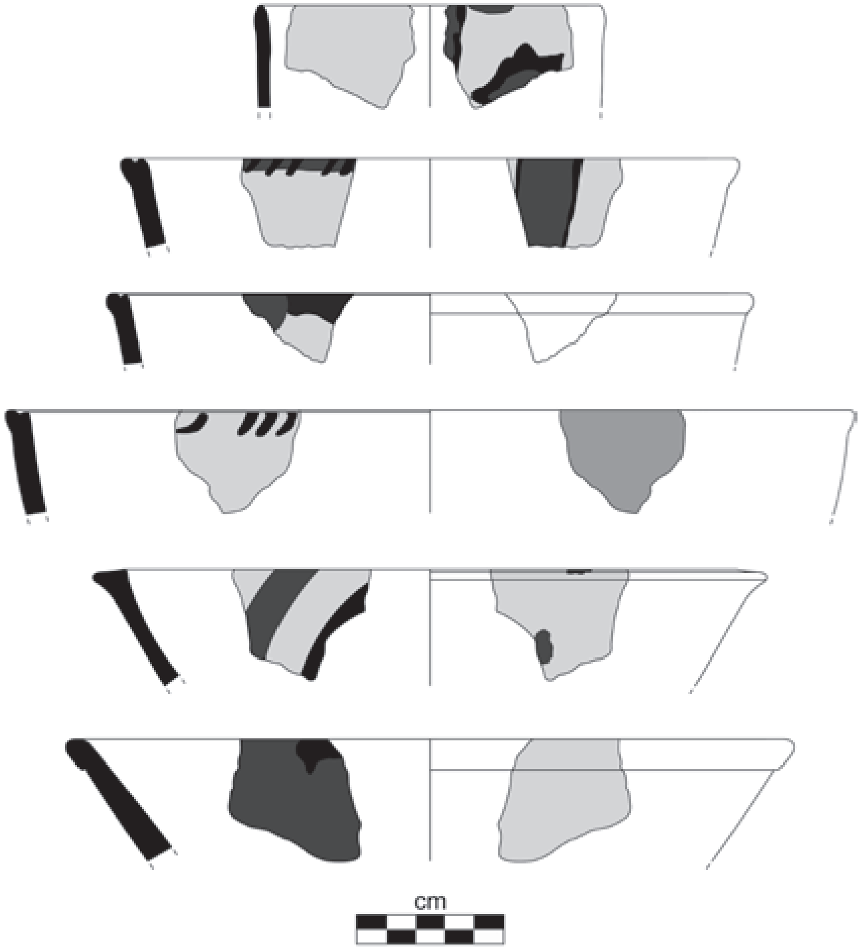

Figure 6.5 Late twelfth century yellowish-green glaze ceramics recovered from refuse pits located inside the castle curtain wall of Salemi. Identification numbers from top to bottom: CAS903, CAS907, CAS906, CAS905, CAS901, CAS904

Norman, Islamic, or even Byzantine Age. This tower is 1,801 m^3 in size and consists of approximately 4,525 t of stonework. Labor costs are approximately 134,000 person-days, necessitating 150 laborers working for three years or some permeation thereof.

The presence of these pits and the sheer absence of any other pre-thirteenth-century features is significant, providing evidence that a substantial amount of matrix and bedrock was stripped from the hilltop, erasing all but the deepest of features from the archaeological record. Removing anthropic fill and disarticulated, decomposing bedrock created a stable

foundation upon which the castle could be constructed. Systematically truncating and leveling the summit of the hill would have been a substantial undertaking during the twelfth or thirteenth centuries, much as it would today. Without any reference to the original height of the summit, calculating the volume of material removed and consequently the labor invested in such an undertaking remains difficult at best.

Phase II – Thirteenth century

Phase II consists of nine architectural elements including the northeast and southwest square towers, the northwest round tower, the curtain wall sections, and a remnant of an 80 cm thick defensive circuit wall located in front of the castle gate. These elements of Salemi Castle were added in the first quarter of the thirteenth century, with the round tower built c. 1239 (Caruso 1998; Maurici 1992; Militello and Santoro 2006).

The three-story round tower stands 25 m high and is characterized by two stacked chambers with ribbed octagonal stone ceilings and a basement with a hemispherical ceiling. The original entrance was a small door placed in the highest chamber, making the tower difficult to access from below. The roof and middle chamber were accessed by a circular staircase placed inside the wall towards the interior of the castle. The majority of the outer facing stonework consists of alternating rows of locally available sandstone blocks cemented with dry-slaked lime mortar and rows of harder Campanella limestone blocks. These were procured (along with the wood) from the hilltop and medieval-era rock quarries of San Ciro approximately 1.5 km away. The average cut rock size used in wall construction was approximately 75 × 50 × 50 cm. The round tower represents the largest building element (2,289 m^3 and requiring 5,680 t of materials) constructed in approximately 170,000 person-days.

The northeast tower dating to this phase collapsed in the late eighteenth or early nineteenth century (Caruso 1998, 680), with some of its stones recovered and used to build a water reservoir in 1934. This tower was presumably square in shape and was essential for enclosing the courtyard and protecting the curtain wall. The location and size of the original northeast tower is easily deduced for our labor estimates using the remaining architecture and the overall trapezoidal design of the castle, with its round tower/three square tower design being common in much of Sicily.

Exterior excavations outside the castle gate revealed an 80 cm thick defensive circuit wall that was presumably used while the castle was constructed or for additional defense. Segments of this circuit wall are still visible on the east side of the castle, but the western extent can only be found beneath the surface. Here, the wall is preserved to a maximum height of 3.2 m in some locations, with upper portions demolished during Phase III, presumably to level off the courtyard in front of the castle gate. Constructed of cracked stones and water-washed cobbles set into a sandy

cement, this wall was placed into a deep wall trench that truncated extant structures and followed the contour of the bedrock beneath through varying depths of anthropic fill.

The cumulative effort to construct the Phase II Salemi Castle included 23,894 t of materials and approximately 687,000 person-days. This would have required a construction period of seven-and-one-half years using a labor force of about 300 workers.

Phase III – Fourteenth century

Phase III consists of two interior fortified rooms, built along the south side of the castle and placed adjacent to the great hall. They were added in the first quarter of the fourteenth century and are both roughly equal in height and integrated with the southeast and southwest towers. Exterior excavations also revealed a large pit near the castle gate that contained straw-tempered medieval roof tiles, yet no temporally diagnostic artifacts. These tile fragments are indicative of a renovation or repair period when old roof tiles were removed and dumped, likely when the two rooms were added to the great hall. These Phase III rooms total roughly 91 m^2 in size and consist of approximately 3,974 t of stonework. Labor costs are approximately 115,000 person-days, requiring the same number of 300 laborers to work for one-and-one-quarter years.

Summary

Salemi Castle required a total of 37,092 t of materials and over 1,076,000 person-days to construct. This is the equivalent of 300 workers laboring for twelve years, with an additional 1,350 agricultural workers having to cultivate 7,923 hectares of agricultural fields for those twelve years. If we assume one in four are of working age (cf. Epstein 1992), we can estimate that Salemi had a population of at least 6,600 people during the thirteenth century.

Architectural analysis for Salemi Castle reveals that it was an average-sized but architecturally complex castle built in three successive building phases, with twelve separate architectural elements that are fairly indicative of the dynamic nature of the growth of the site. The first building episode (Phase I, pre-thirteenth century) consisted of a single tower located in the southeastern corner of the site, and consisted of 11,801 m^3 of stone taking 134,134 person-days to construct. When this tower was constructed is a matter of debate, and it is difficult to ascertain exactly how large and how extensive it was. It is clear however, that Salemi was an important enough agricultural region that warranted an early fortification by the Byzantine and/or the Arab Period. Phase II (thirteenth century) renovations were the most impressive of the three phases in terms of size and complexity, measuring 9,213 m^3 of stone and taking 687,331 person-days to complete, while Phase III (fourteenth century) consists of further elaboration of the two

south towers on the inside of the castle courtyard consisting of 1,552 m^3 of stone and requiring 115,712 person-days to construct.

Although Salemi Castle was built in three phases, the majority of its architectural features were constructed during a relatively brief episode, between 1200 and 1239 (the Swabian Period). This sudden expansion and labor burst was imposed from outside the community by political elites whose goal was to integrate and situate the community of Salemi within the greater political sphere of the kingdom. The thirteenth century expansion of Salemi Castle was not unique and must have been an impressive event throughout many of the island's urban centers, with the expansion of a great many castles representing a political accomplishment that had no contemporaneous comparison. After Swabian rule, island-wide consolidation – and a network of "founding citadels" – was complete. Later liege lords made only minor modifications to a number of these castles, such as Salemi's modification of the great hall and the addition of two flanking fortified rooms.

While these numbers might be specific to Salemi, they likely are indicative of similar labor mobilization efforts going on at nearby castles such as Calatubo and Alcamo. Similar to Langeais Castle in France, the construction of Salemi Castle was a cost-effective military measure that minimized the creation and maintenance of large numbers of mounted cavalry. Understanding the labor efforts put into castles can help us to better understand when such military measures were seen as most needed in the past. However, not all castles had the same amount of labor invested in them, and further research into labor costs throughout larger areas of Sicily can help us to understand where more efforts were focused spatially.

Labor mobilization: western Sicily

The costs calculated for Salemi Castle may be used to obtain a general idea of how labor was differentially invested at other castles in western Sicily. One method of extrapolation is to identify a valid proxy measure of energetic person-days. Because labor energy costs (acquisition, transportation, and construction of architectural elements) represent a measure of the degree of organizational production, it is likely that other site characteristics such as total area (m^2), total wall perimeter (m^2 – measured by using linear wall distance times its thickness), or total stone volume (m^3) are acceptable measures of labor investment. A proxy measure such as this is valuable when detailed energy costs cannot be easily calculated.

To identify a workable proxy labor measure, three Spearman's correlation coefficient tests were run using these 12 Salemi architectural elements ($n = 12$). The first test, the total area (m^2) of each architectural element, does not correlate with person-days at a statistically significant level ($R = 0.16084$, $p > 0.61752$), and therefore is a poor measure for estimating labor investment costs. The second test, the total wall area (perimeter measured in m^2) correlates with person-days at a statistically significant level

(R = 0.7986, $p < 0.00184$), indicating that perimeter (that is, wall area in m^2) may be used as a proxy measure of castle labor mobilization for heuristic comparative purposes. The third test, the total stone volume of each architectural feature (m^3), correlates with person-days at a statistically significant level (R = 1.0, $p < 0.00001$) and also serves as an excellent proxy for labor energetics. Therefore, utilizing wall perimeter and/or the volume of stone instead of full person-day calculations has utility for quick castle-to-castle comparisons in future studies.

Table 6.4 presents the total perimeter for 14 of the largest castles in Trapani District, Sicily, calculated using satellite imagery and previous site drawings. Wall perimeter was used instead of total stone volume to calculate labor investment because many of these castles are in a state of ruin or disrepair, making wall heights difficult to measure. Wall lengths and thicknesses for both curtain wall and tower features, on the other hand, were easily identified and traced using GIS software and total wall perimeter was measured in square meters with the century of initial construction for each castle determined using historical sources (e.g. Tuzzolino et al. 2006). The mean wall perimeter for these castles (the castle at Mazara is unmeasurable; only a gateway remains) is 528 m^2, the largest being 896 m^2 (Salemi), and the smallest 259 m^2 (Marsala). The construction projects of the largest five castles were all initiated in the eleventh century, coinciding with the Norman invasion and territorial consolidation.

Figure 6.6 illustrates the topographic variation of each castle in western Sicily. Castello di Terra and Erice, both near the political center of Trapani,

Table 6.4 The 15 largest castles remaining in Trapani District, Sicily

Castle	*Earliest age* [a]	*Total wall perimeter* (m^2) [b]
Salemi	Eleventh	896
Castello di Terra	Eleventh	846
Erice	Eleventh	835
Castellammare	Eleventh	684
Calatubo	Eleventh	626
Colombara	Twelfth	508
Calathamet	Tenth	501
Castelvetrano	Twelfth	429
Bonifato	Fourteenth	414
Partanna	Fourteenth	375
Catalafimi	Twelfth	370
Segesta	Twelfth	360
Alcamo	Twelfth	288
Marsala	Thirteenth	259
Mazara [c]	Eleventh	?

[a] Earliest age of construction is determined by historical references.
[b] The total wall perimeter is measured in square meters and determined by calculating the remaining wall areas.
[c] Only a single gateway remains of this important castle.

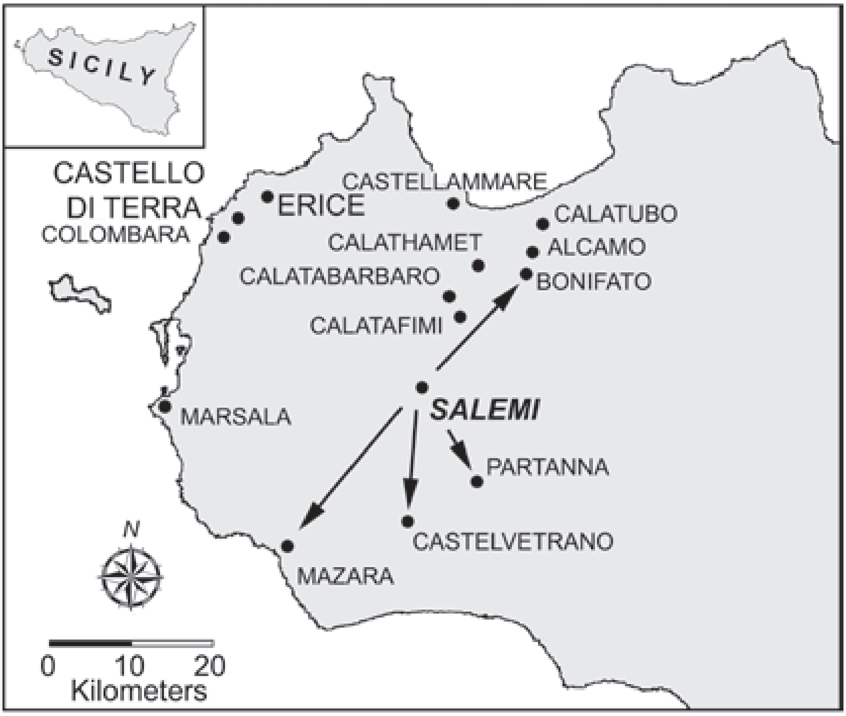

Figure 6.6 Castles of western Sicily. Circle size indicates the relative perimeter (in square meters) of each castle. Arrows indicate direct line-of-sight castle intervisibility

rank highest in total wall perimeter and thus were important labor investments. Salemi also ranks very high and, as the largest castle in the interior, likely represented a position of strategic importance. Indeed, Salemi has direct line-of-sight to both castles on the south coast and castles near the north coast. Therefore, Salemi's position seems to have served as a strategic linchpin for an important north-south, coast-to-coast communication network of intervisible castles.

Conclusion

Castles are one of the defining examples of monumental architecture seen in medieval Europe, and yet over the last half millennium people seem to have forgotten just what, exactly, their purpose was. While it is clear that our position, and the position of a great many other scholars (e.g. Bachrach 1984; Bachrach and Bachrach 2017; Hogg 1981; Viollet-le-Duc 2005), is that castles served a functional purpose, others would disagree and emphasize their more symbolic aspects (e.g. Askew 2016; Johnson 2002). Though this

debate will likely continue, we have demonstrated the enormous amount of labor and resources necessary to build and maintain a strategically important Sicilian castle.

Salemi was an ideal choice for a labor investment study. Its early existence shows that it was one of the "founding citadels" that the Normans used to take and keep control of Sicily, and its later trapezoidal design with a tower on each corner is not at all atypical for the island. While the present layout of Salemi Castle may be different than many of the Norman castles in England, its early function seems to have not differed markedly from the castles built to take and hold control over England (cf. Morris 2016). Additionally, its position at the center of a hilltop settlement places it in the context of the greater model of *incastellamento* seen across larger parts of Christian Europe.

Over a decade of excavation at Salemi Castle has enhanced our understanding of the castle's architectural chronology. This knowledge allows us to quantify the labor costs of its three phases, and then contextualize each within its relative historical period. The total labor costs for the construction of the Salemi Castle were valuable in determining proxies for estimating labor investment in castles where as much detail on their construction is not known. Total wall perimeter and volume of stone both have statistical correlation with labor investment and can be used to better understand the labor needed to construct castles in Sicily. Thus, from this work, we can begin to more clearly understand some of the functional roles castles had in society based on the combined analysis of their geospatial position and the amount of resources required for their construction.

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7 Labor recruitment among tribal societies

An architectural energetic analysis of Serpent Mound, Ohio

Jamie L. Davis, Jarrod Burks, and Elliot M. Abrams

Introduction

The majority of architectural energetic analyses to date have focused on construction projects orchestrated by powerful state systems. Large ceremonial and funerary construction throughout the world points to the considerable building capabilities of tribal groups. It is important to conduct comparable architectural energetics analyses on non-state societies, particularly tribal societies, to understand their achievements and context in world archaeology.

In the midcontinent of the United States and especially throughout the Ohio Valley, tribal societies traditionally termed Adena (Early Woodland; c. 500–50 BCE) and Hopewell (Middle Woodland; c. 50 BCE–350 CE) orchestrated the construction of some of the largest earthen monuments in the preindustrial world. These "ancient monuments of the Mississippi Valley," as termed by Ephraim Squier and Edwin Davis (1848), reflect the organizational capacity of small tribal communities working in unison and, in some respects, materialize the very ideal of what constitutes a tribal society (Service 1962). Yet despite their scale and complexity, the earthworks designed and built by these Early and Middle Woodland tribal societies throughout the Ohio Valley have received very little scrutiny within architectural energetics, a method that explicitly seeks to illuminate organizational capabilities in the past through the time-labor analysis of architecture. There have been limited studies of Early Woodland earthen mounds in the mid-Ohio valley (Shryock 1987; Mainfort 1989; Abrams and LeRouge 2008). Similarly there has only been one such study explicitly targeting the larger earthen complexes of the Middle Woodland period (Bernardini 2004).

In this chapter, we offer an architectural energetic analysis of Serpent Mound. Though the debate continues as to its age (see Hermann et al. 2014; Fletcher et al. 1996; Romain et al. 2017), Serpent Mound is one of the most complex earthen construction projects built by Early Woodland tribal societies in the Ohio Valley. A wide range of new data has contributed to a better understanding of the construction chronology of Serpent Mound and the use of the hilltop through time. These new data sets include: 1) multiple

radiocarbon dates that give a tight window for the construction period; 2) a geomagnetic survey that demonstrates that the form of the serpent went through several alterations; 3) a photogrammetry model that has mapped Serpent Mound with unparalleled accuracy allowing for accurate volumetric measurement for the first time. These new data sets, along with the most site-appropriate cost estimates, allow us to accurately determine the labor expenditure in the serpent's construction. As a result of this cost analysis, this chapter discusses the labor system responsible for building the Serpent Mound and the sociopolitical implications for Early and Middle Woodland societies over time. Overall, we emphasize that expanding the sociocultural contexts to which architectural energetics is applied, especially contexts not typically connected with monumental construction, allows for expanded considerations of changes in labor and sociopolitical dynamics.

History of Serpent Mound

Serpent Mound State Memorial is located on a 30-m-high bluff overlooking Ohio Brush Creek, about 40 km (25 miles) north of the Ohio River (see Figure 7.1). The site consists of a serpentine embankment, a moderate-sized

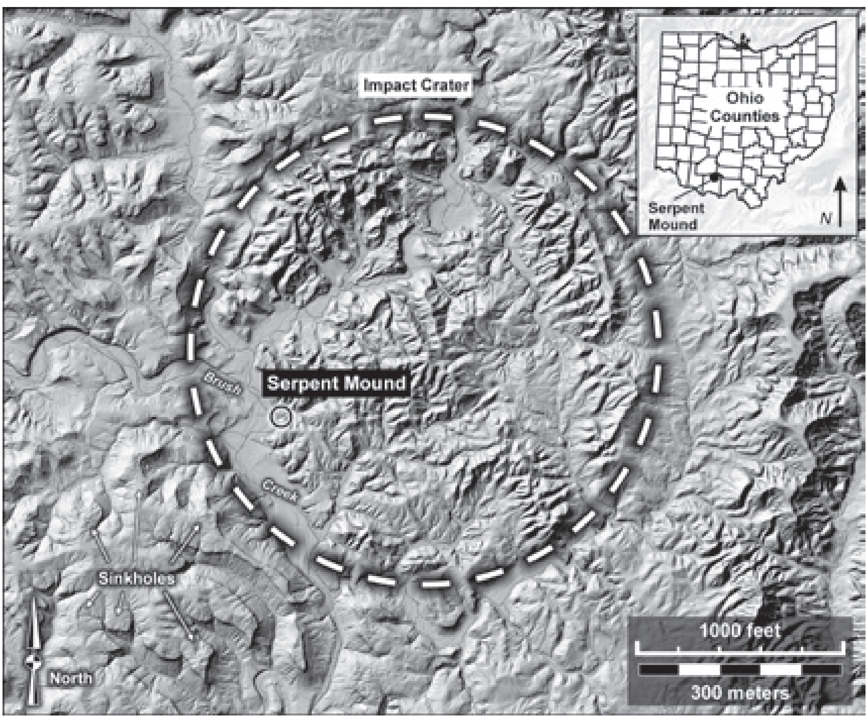

Figure 7.1 Shaded relief map of the Serpent Mound area based on OSIP LiDAR data

Adena mound, two small mounds, three sinkholes, a tremendous amount of buried archaeological features, and the extant and demolished remains of park-related facilities from several generations of park construction and maintenance (see Figure 7.2). The hilltop containing the site is surrounded by distinct landforms. To the east and beneath the park, a circular, heavily eroded area covering about 31 km^2 marks the location of the Serpent Mound Crypto Explosion Structure, a meteorite impact crater from about 300 million years ago (Hansen 1994, 1998; Reidel et al. 1982). The hilltops to the west, while much flatter and more inviting for earthwork construction, are pocked with numerous sinkholes.

Serpent Mound and the surrounding area are in an unglaciated portion of southern Ohio. The serpent and the bulk of the area within the park occur

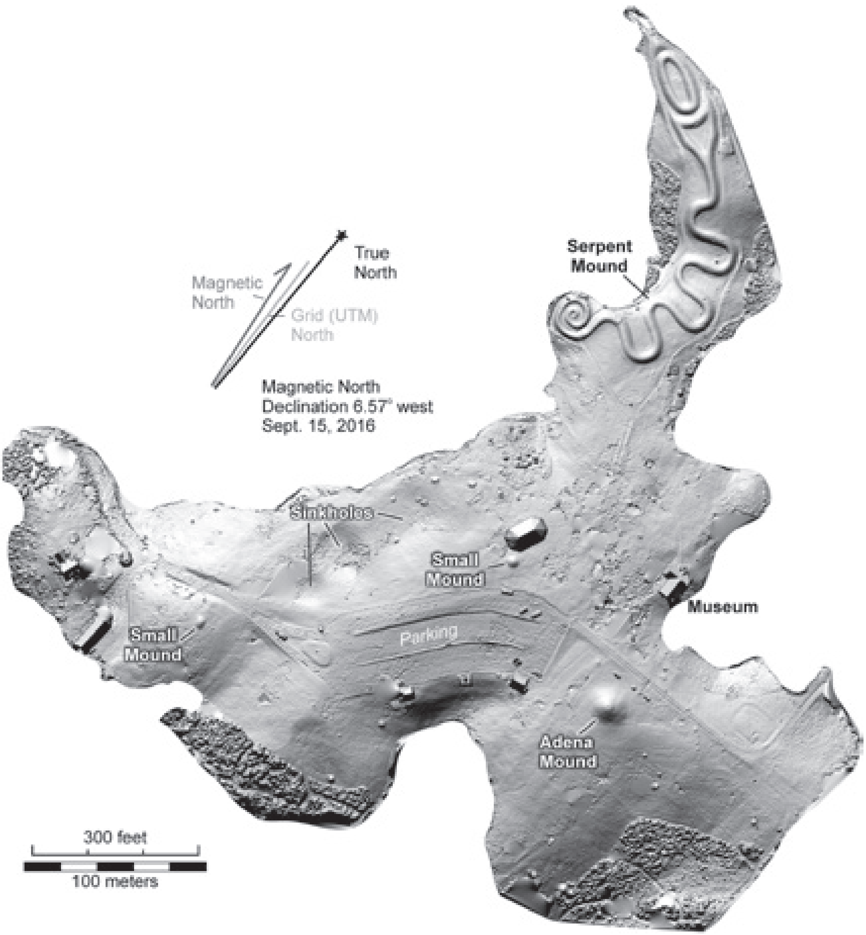

Figure 7.2 A photogrammetry-based digital surface model of the hilltop within Serpent Mound State Memorial

on Bratton series soils (USDA 2006). Bratton silt loams form on upland landforms covered by a thin layer of loess (windblown silts). They typically overlie a clayey layer of weathered limestone or dolomite bedrock. These are standard forest soils, with a light colored silty A horizon (c. 0–20 cm) above a series of silty clay to clay horizons extending down to about 80 cm below surface. Bedrock often occurs at about 90–100 cm below surface. In some areas of the site, such as around the serpent itself, bedrock is exposed at the surface because of erosion and soil borrowing to create the serpent. In other areas, such as filled erosional gullies or sinkholes, bedrock is much deeper. The steeper slopes of the survey area are covered by Opequon silty clay loam soils (USDA 2014). These soils lack the overlying loess deposits of their upslope neighbors, and they tend to be quite thin – less than 50 cm of sediment sitting on bedrock. Opequon soils also have soil horizons (A and Bt) similar to those found upslope, though with more clay.

Much of what we know about Serpent Mound is based on early work in the 1800s. Squier and Davis (1848) were the first to map and study the serpent in the 1840s (see Figure 7.3). At that time the earthwork was still covered in forest and had yet to be plowed. Though their map is somewhat inaccurate, they report that the serpent's embankment ranged up to 1.5 m (5 ft) in height. They also were the first to note the location of the larger Adena mound and several other site features. A tornado in the 1860s destroyed much of the forest covering the serpent and opened up the earthworks to plowing. Not long thereafter, in the 1880s, the first fairly accurate maps of the serpent were made (Holmes 1886; MacLean 1885).

Frederic Putnam conducted the most extensive excavations to date at Serpent Mound in the late 1880s and facilitated the preservation of the site into what has become Serpent Mound State Memorial (Putnam 1890). Putnam probed the serpent with a number of trenches, showing that it was constructed with sediments and rock common to the surrounding hilltop. He also completely excavated the three mounds within the park. Excavations elsewhere on the hilltop located a Late Prehistoric period (1000–1650 CE) Fort Ancient settlement, other Early Woodland period (c. 500–50 BCE) Adena burials and deposits, and objects spanning the Early Archaic period (8000 BCE) through the Late Prehistoric period (1650 CE).

Putnam capped off his work within the park by rehabilitating Serpent Mound. Before-and-after photographs from the 1880s show that this work increased the height of the serpent with sediments scraped up from the ground adjacent to the embankment. While Putnam's crews excavated and moved a significant amount of soil, it is uncertain if additional soils were added to the serpent from elsewhere within the park. Field survey and detailed map comparisons in 1918 by Willoughby (1919) show that Putnam's rehabilitation of the serpent did not change the serpent's shape (see Figure 7.3), only its height. Subsequent mapping efforts in the 1980s refined the shape of the serpent on maps, established a celestial north line in proximity to the serpent, and identified possible astronomical alignments

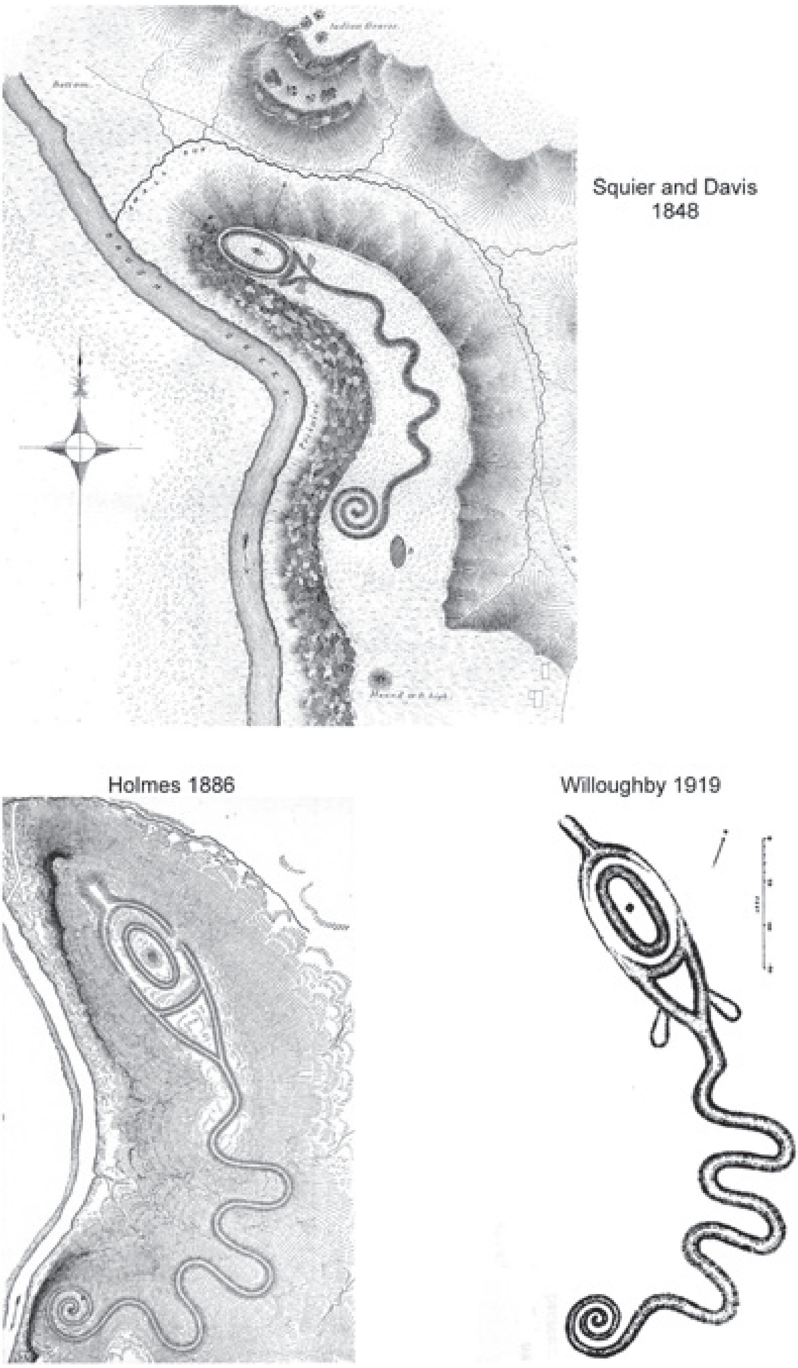

Figure 7.3 Early maps of Serpent Mound by Squier and Davis (1848), William Holmes (1886), and Charles Willoughby (1919)

(e.g. Hardman and Hardman 1987; Fletcher and Cameron 1988; Romain 1987, 2000).

Since Putnam's work in the 1880s, a variety of smaller excavations have taken place at various locations around the park, including within the serpent. Utility line work has uncovered significant evidence of the Fort Ancient occupation (Thompson et al. 2013), as well as a feature and artifacts from the Early Woodland period (Schwarz and Lamp 2012). Other resource management projects have encountered limited or no Native American cultural materials (e.g. Pansing 2012; Pickard and Pansing 2005, 2006). Nevertheless, excavations in various locations around the park show that the hilltop surrounding the serpent contains extensive evidence of Native American occupation.

In addition to excavation, geophysical survey projects within the park also have identified numerous features. Ground-penetrating radar survey has located a number of anomalies within the body of the serpent (e.g. Akers 1988; Thompson et al. 2013) and elsewhere in the park (Burks 2017). A complete magnetic gradient survey of the serpent and the mowed areas within the park has revealed hundreds of anomalies of potential archaeological interest (Burks 2017). Most are possible pit-type features that may be related to the Fort Ancient settlement located south of the serpent. The most intriguing discovery is what appears to be an erased portion of the serpent's body. A 2011–12 magnetic survey uncovered a large curvilinear anomaly near the serpent's neck (see Figure 7.4) that is the same size and shape as the extant undulations of the serpent's body (Burks 2012). Excavations in 2012 confirmed this anomaly to be associated with a distinct soil feature. Burks (2012; Herrmann et al. 2014) suggests this curvilinear feature was once part of the serpent but was erased at some point in antiquity.

Interest in the age of Serpent Mound has increased recently with the publication of new radiometric dates from the base of the serpent's embankment. Six accelerator mass spectrometry (AMS) dates on bulk soil samples collected from cores at several locations along the length of the serpent's body suggest that the earthwork was first built within the 400 years after 321 BCE (Herrmann et al. 2014). At first, these new dates seemed to contradict the first radiocarbon dates published for Serpent Mound by Fletcher and colleagues (1996), who concluded that the serpent was built after 1000 CE. However, Herrmann et al. (2014) and Romain et al. (2017) argued that the range of radiometric dates, the erased portion of the serpent from the magnetic data, as well as other evidence, point to a complex history of construction and maintenance that spanned 2,000 years. Thus, the serpent we see today is the end result of more than one earthmoving event or period. However, the primary earthwork described below was built in a rather short duration sometime within this 400-year period. Both projects confirm that the serpent was built, in general, with yellowish brown silty clay – the same kind of sediment located in the B horizon all across the hilltop.

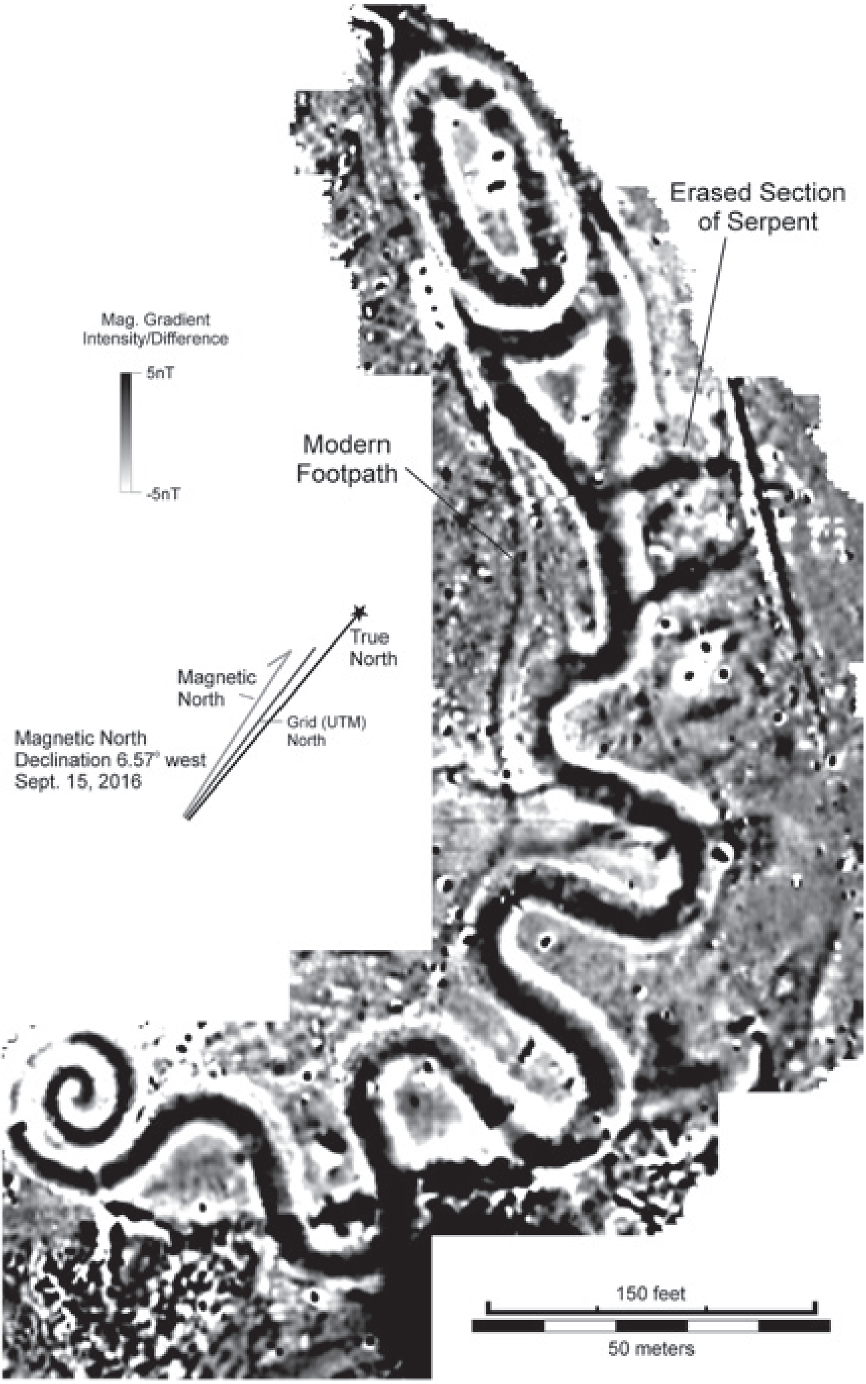

Figure 7.4 Magnetic gradiometer data collected in 2011–12 (adapted from Burks 2012)

Deriving the volume of Serpent Mound from a photogrammetry model

There have been several attempts at estimating earthwork volume in the Ohio River Valley from both mounds and enclosures (Abrams and LeRouge 2008; Bernardini 2004). These estimates relied on data derived from excavations and rudimentary geometry. Unfortunately, excavations are destructive (in that new volume estimates are no longer possible after archaeological intervention) and previous uses of geometry have been too rudimentary to produce precise estimates. While numerous conical mounds have been excavated and determining the volume of a cone is fairly simple, no mound is a true cone. Therefore, estimates based on simple geometry can vary significantly from the actual mound volume. Simple estimates based on geometry are even more difficult for computing the volume of linear earthworks, especially those on complex landforms such as Serpent Mound.

Unmanned aerial vehicle (UAV) based photogrammetry is one solution for developing accurate and precise estimates of earthwork volume. It provides a means to accurately map Serpent Mound and the complexities of the landform on which it was built. Once the serpent's embankments and the surrounding surface have been accurately mapped, Serpent Mound can be isolated and its volume can be determined.

Photogrammetry has been used in archaeology for several decades. With recent advances in consumer computing technology, software, and UAVs, photogrammetry has become a versatile tool used for everything from basic documentation to complex analysis (Campana 2017; De Reu et al. 2013). The photogrammetry work at Serpent Mound began with the capture of hundreds of images using a DJI Inspire 1 Pro T600 (UAV) with a Zenmuse X5 camera and the default DJI MFT 15mm F/1.7 lens. To collect the photographs, the UAV flew an autonomous flight at a height of 61 m on a gridded pattern, with approximately 80% overlap between the orthogonal photographs. This camera system, coupled with the flight height of 61 m, produced a ground sampling distance (GSD) of approximately 1.5 cm per pixel. However, the photographs were collected during the month of August and numerous tree branches and leaves obscured the view of the serpent, so manual flights and hand-held photographs were used to capture additional oblique photos to maintain a consistent resolution along the length of the effigy mound. Photographs from the manual flight were taken from heights between 4.5 and 9 m; the Zenmuse X5 camera was attached to the DJI Osmo mobile gimbal to capture the hand-held photographs. Together, these photographs from lower elevations provide a GSD of the serpent below 0.3 cm/pixel.

The Pix4D Mapper software was used to create the photogrammetry model. However, this software could not seamlessly match the oblique photos to the higher altitude nadir photos; therefore, the two sets of photographs had to be manually tied together. Ground control points (GCP) were

not used in the creation of the model for lack of access to an RTK GPS system. However, Davis and numerous other researchers have found that photogrammetry software that provides proper lens and camera calibration, along with the onboard GPS, can produce models that have accurate special context; they simply are not tied into a real-world coordinate system (Carbonneau and Dietrich 2017). With the oblique and nadir photographs seamlessly tied together, a very high resolution, spatially accurate model of Serpent Mound has been produced.

The photogrammetry software is capable of producing a digital surface model (DSM), but in this case a dense point cloud was exported and other GIS software was used to produce the DSMs and figures, including ArcGIS 10.5, ArcScene 10.5, Surfer 10, and CorelDraw 16. Although the photogrammetry model had a resolution below 0.3 cm/pixel, the model is a surface model; thus it includes grass and any other foreign objects that happened to be lying on the mound at the time of the photography. The serpent did receive a fresh mowing prior to the UAV flights but negligible non-mound objects, mainly grass, remained on the surface of the mound. To minimize the grass effect in the final DSM, an initial DSM with a resolution of 5 cm was created and processed multiple times through a low pass Gaussian filter.

Once the photogrammetry data were converted into a DSM, they could be manipulated like any other raster data set. To get a better view of the serpent and to make working with the DSM easier, the serpent and its immediate surroundings were isolated from the rest of the landscape (see Figure 7.5). Linear profiles extracted from the DSM show that most of the serpent has a semi-circular shape in profile (see Figure 7.6); or rather, one more closely matching a portion of a semi-circle approximately one m tall and six m wide. Further manipulating the DSM by flattening the serpent reveals that the serpent generally ranges between 70 and 90 cm tall relative to the natural ground surface, with the highest portion rising slightly over one m above the surface (see Figure 7.7).

The general profiles and the height above the surface provide a means to approximate the serpent's volume (see Figure 7.8). This volumetric estimate can serve as a comparative measure against the volume calculation of the serpent generated from the 3D photogrammetry model. Using a single height (80 cm) of the most consistent portion of the serpent between the base of the neck and the coil of the tail produces a volume estimate for the serpent's 259.5-m-long body of roughly 830 m^3 (Figure 7.9). The real effigy, however, does not follow a uniform height and width, and in general spans less than 6 m wide. Thus, the actual volume should be less than this theoretical volume. To directly calculate the volume of the photogrammetry model, the DSM in the interpreted area of the actual serpent was converted to two triangular irregular networks (TINs), one of the serpent's surface and another of the surface running underneath the serpent. The software then calculated the volume difference between the two TINs.

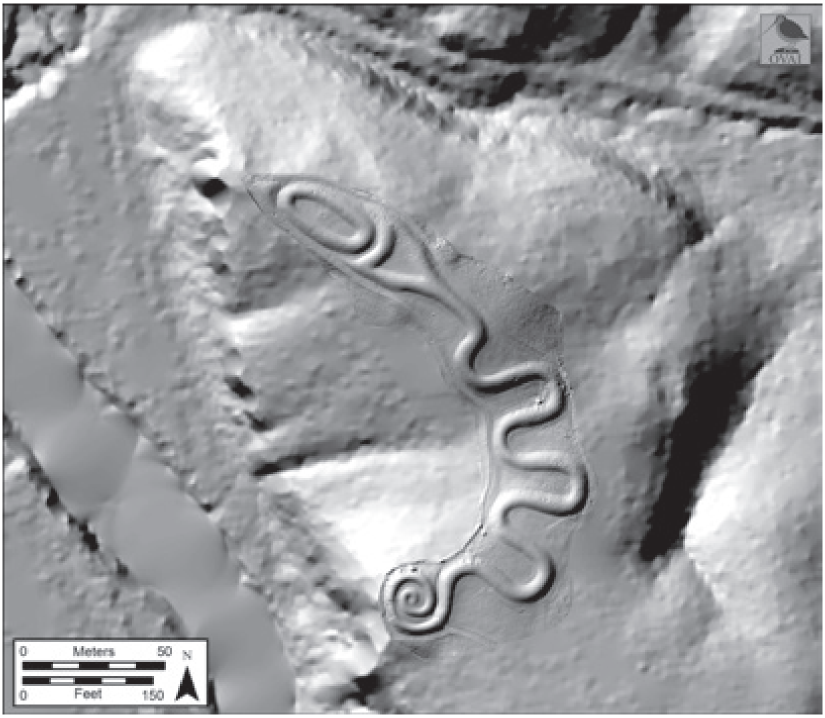

Figure 7.5 A hillshade rendering created from the portion of Serpent Mound isolated from the total photogrammetry model, overlaying a hillshade of the Ohio 2 m LiDAR data

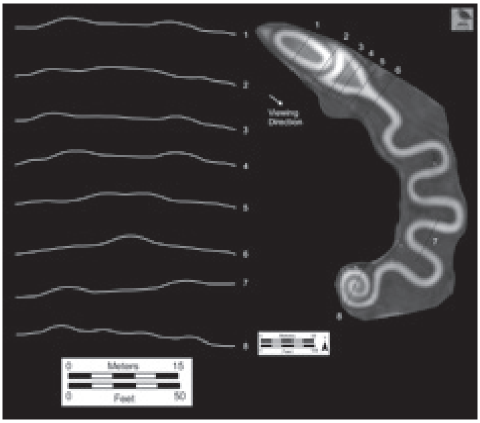

Figure 7.6 Cross-sectional profiles show that Serpent Mound consists of varying complex shapes that change throughout the earthwork. In general, the shape of the serpent, especially in the body, tends to be in the shape of a part of a circle that is 80 cm tall and 6 m wide

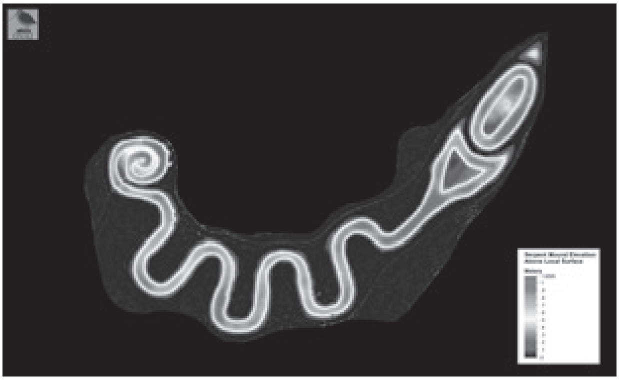

Figure 7.7 By flattening the serpent through removing the slope from the natural landform surrounding Serpent Mound, the height of the serpent above the local surface can be determined. The height of the serpent generally ranges between 70 and 90 cm above the local surface, with the tallest portions of the serpent reaching slightly over 1 m

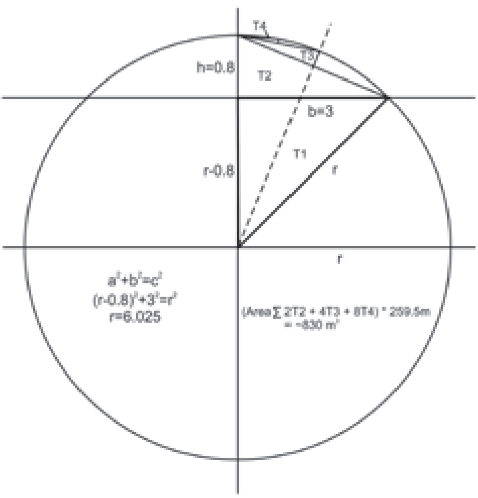

Figure 7.8 Based on the cross sections of the serpent and the height above the local surface, a volume estimate can be derived through geometry as a benchmark for the expected volume calculated from the photogrammetry model

The software-calculated volume of the 259.5-m main body of the serpent between the base of the neck and the coil of the tail was 747.5 m^3, which is very close to the estimated calculation. Applying the same techniques to the entire serpent, the following volumes were computed: 1,031.5 m^3 for the serpent, 163.4 m^3 for the oval, and 7.1 m^3 for the triangle above the oval. Combining these together produces a total volume for Serpent Mound of

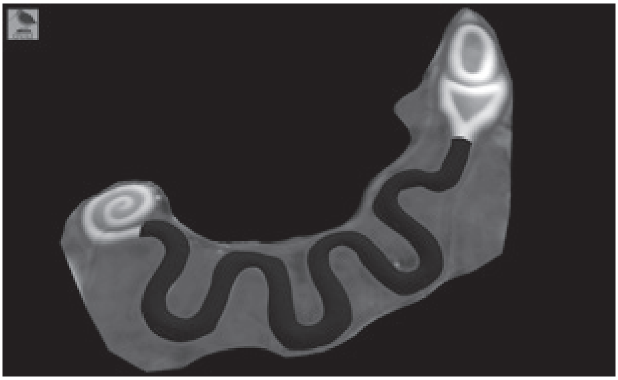

Figure 7.9 To test the accuracy of the photogrammetry model, the geometric volume calculation for the most consistent portion of the serpent from the base of the neck to the tail derived from the process described in Figure 7.8 produced a volume of 830 m^3. The photogrammetry model for the same portion of the serpent produced a volume of 747.5 m^3

Figure 7.10 The triangular irregular network (TIN) used to determine the volume of Serpent Mound. The total volume summed to be 1,202 m^3

1,202 m^3 (see Figure 7.10). It is important to note that only the volumes of the embankment walls were calculated. None of the surface beneath or next to the serpent was included.

Architectural energetics of Serpent Mound

A distinct and explicit protocol was followed for the quantification of the Serpent Mound energetics as outlined by Abrams and McCurdy (Chapter 1). The structure was reconstructed "on paper" to its original form, allowing us to quantify its architectural components and the volume of material in each

component. Unlike complex buildings that have many components and raw materials, there were relatively few materials used in the construction of Serpent Mound. Soil is the primary component, with limited amounts of stone. Both could have been acquired relatively close to the construction site. Based on the techniques described above, the volume of soil in Serpent Mound is 1,202 m^3.

The presence of only one or two general types of soil eliminates the issue of multiple distinct sources. In some construction of earthworks, for example at Hopeton earthworks, clayey soils of distinct colors were used as separate construction events (Lynott 2014). The use of relatively few soil types at Serpent Mound indicates that this sediment was dug from the adjacent solum of the ridge or slopes of the ridge. This soil however did not come from directly below the area where the snake effigy was built. In addition, no distinct barrow pits have been identified at the site. As such, in our analysis we assume that the average distance from the earthwork to the varied sources of soil was 100 m.

To actually construct the earthwork, the outline of the snake was first laid out in some manner on the relatively undisturbed surface of the ridge – the topsoil may have first been removed (cf. Herrmann et al. 2014). Construction began as early as c. 321 BCE. It is possible that the entire Serpent Mound was constructed in one episode. Distinctions in depositional layers likely are related to loading from different sources rather than loading from different times. The lack of any topsoil development between loading layers indicates that construction took place in a relatively short period of time. This conclusion also is supported by the tight clustering of radiocarbon dates from the base of the mound (Hermann et al. 2014, 121). In fact, this clustering of radiocarbon dates suggests that construction of Serpent Mound was "a single-phase event that occurred very rapidly (that is, within several years)."

The significant (meaning costly) building activities only involved quarrying the soil, then transporting and depositing that soil at the site of construction. Although tamping the soil and shaping it into the desired form certainly were activities performed by the builders, these are deemed of such low cost that they do not warrant quantification.

In terms of cost estimates, the figure of 2.6 m^3 of earth quarried by a person within a day (Erasmus 1965, 285) is the standard (Bernardini 2004; Abrams and LeRouge 2008). However, a new and more site-specific estimate for quarrying the soil is used here. Milner et al. (2010) replicated digging silt loam soil using a chert digging tool, a soil type comparable to the subsoil used in Serpent Mound, as opposed to the sandier soil used in the Erasmus digging experiments in Mexico. Although their sample size was relatively small, Milner et al. (2010, 108) arrived at a mean cost of 1.64 m^3/p-d (person-days) and a median cost of 1.84 m^3/p-d. These contextualized costs more accurately reflect the increased difficulty of quarrying denser soil than does the 2.6 m^3/p-d estimate. Therefore, in the present analysis, we use

1.7 m^3/p-d based on Milner and colleagues' two values as the cost estimate for quarrying earth. We recommend that future analyses similarly apply this rate of digging in silty loam soils (typical of the A and B horizon) of the US Midwest.

Assuming an average distance of 100 m from the source(s) of soil to that particular section of the earthwork being built, the rate of transporting soil based on Erasmus' transport experiments (1965, 284) is 2.05 m^3/p-d. This rate is comparable to those estimated from the ECAFE (1957) formula.

The final step is simply articulating the volume of soil with work rates. The volume of 1,202 m^3 dug at a rate of 1.7 m^3/p-d required 707 p-d. That same volume transported at a rate of 2.05 m^3/p-d required 586 p-d, for a total of 1,293 p-d.

Discussion

Based on an accurate and contextual volumetric assessment and cost estimation, we can offer inferences on the construction of Serpent Mound and other Eastern Woodland earthwork constructions. First, we humanize the cost estimate of 1,293 p-d based on our understanding of the people who would have been carrying out this work. The current archaeological record and generally accepted view suggests that the Early Woodland communities within the mid-Ohio River Valley and adjacent areas lived in small, relatively sedentary hamlets of approximately 12 residents each, spaced 2 to 3 km across the landscape (e.g. Abrams and Freter 2005; Robertson et al. 2008; Schweikart 2008; Stothers and Abel 2008).

The current evidence suggests that the construction of Serpent Mound occurred relatively quickly, and several possible scenarios could characterize the organization of the construction labor (see Table 7.1). In the quickest construction scenario, the construction of Serpent Mound occurred over a five-day communal event. In that scenario, the 1,293 p-d cost estimate translates to 259 people involved in construction. If each hamlet within the larger regional community provided four people to the labor force, then some 65 hamlets participated in the construction of Serpent Mound. In the longest construction scenario, the construction of Serpent Mound occurred in a five-day construction period annually for 5 consecutive years, involving some 52 people from 13 hamlets.

Table 7.1 Options for time and labor required to build Serpent Mound

Days	*People*	*Hamlets*
5	259	65
10	129	32
15	86	21
20	65	16
25	52	13

The above discussion does not consider the removed coil and the reconstruction of the neck and head area of the serpent. One hindrance remains: the state of the serpent prior to this reconstruction is not known. Were the alterations made after the base was laid but prior to the full construction of the original serpent? Or, was the original serpent form complete for many years with the alterations made due to erosion or change in style? Or, was it a design flaw with the original layout; perhaps the builders could not construct the head that they wanted with the extra coil? We do not know the answers to those questions. We do know, however, that the erased coil represents an alteration that not only had to be decided upon, but also potentially added labor cost to the construction but at a much later date.

The second inference that can be made from the Serpent Mound labor cost estimate involves comparing Serpent Mound to other earthworks in the mid-Ohio Valley. As is our caveat, only a small sample of earthen structures has yet been quantified. Abrams and LeRouge (2008, 225) provide volumes and cost estimates for several small earthen Early Woodland constructions in the Hocking River Valley, although they used the 2.6 m^3/p-d cost for digging earth and a 10 m distance to soil sources (and thus a 15 m^3/p-d rate of transport). Keeping the same rate of transport but reducing the earth digging costs to 1.7 m^3/p-d, the figures in Table 7.2 represent reformulated p-d cost estimates for 13 small Early Woodland earthen mounds. Two general parameters characterize construction of small Early Woodland burial mounds: 1) the construction involved a limited number of people working, perhaps five days per year as an order of magnitude estimate; 2) importantly, construction likely did not exceed a few years.

When we compare the Serpent Mound labor costs to those of the Early Woodland burial mounds within the Hocking River Valley (see Table 7.2), we see that Serpent Mound required far greater labor than did the typical

Table 7.2 Comparative energetic costs for Early and Middle Woodland earthworks

Earthwork	*Period*	*Volume (m^3)*	*Person-days*
Merriman 1	EW	12	8
Merriman 2	EW	13	8
Brown	EW	16	10
Dargusch	EW	17	11
Johnson	EW	23	15
Daines 3	EW	26	17
Daines 1	EW	38	25
Boudinot	EW	39	26
Peach Ridge 2	EW	66	43
Daines 2	EW	111	73
Dow	EW	129	85
Rock Riffle Run	EW	130	85
French	EW	212	139
Armitage	MW	316	207

small earthen mound of the same time period. Those small Early Woodland burial mounds required limited time and relatively few construction participants. Further, we infer that those participants aggregated at a mound location from a limited distance or region – perhaps a single creek or river watershed. From the architectural energetics assessment of Serpent Mound, however, we infer that more participants from a broader region constructed Serpent Mound.

While the construction effort of Serpent Mound exceeded that of small burial mounds within our example from the Hocking River Valley, other Early Woodland constructions far exceeded the size of Serpent Mound. The Grave Creek Mound in Moundsville, West Virginia and the Miamisburg Mound in Miamisburg, Ohio represent two of the largest Early Woodland earthen constructions. The Grave Creek Mound's staggering 32,000 m^3 volume, as calculated from a photogrammetry model by Davis, dwarfs the construction size and effort of Serpent Mound. The difference between Serpent Mound and the large Early Woodland mounds, however, is the amount of time that encompassed the final construction. Serpent Mound appears to have been built within a relatively short amount of time. On the other hand, excavations have determined that many large Early Woodland mounds were constructed in multiple building episodes that sometimes spanned centuries (e.g. Dragoo 1963; Hays 1994). It seems likely that the labor needed to construct each building episode of these large mounds matched or exceeded that of Serpent Mound.

When comparing Serpent Mound to Middle Woodland Hopewellian earthworks, an entirely different picture of construction scale emerges. The Ohio Middle Woodland constructions of the Scioto River Valley, the Miami River Valleys, and the Newark region represent some of the largest earthen constructions in North America. Fort Ancient in the Little Miami River Valley and Hopewell Mound Group in the Scioto River Valley each have main embankments that stretch for over 4.8 km, and each enclosed a space over 40 hectares with earthen walls measuring 2 to 5 m tall.

While Bernardini's (2014) estimates of energetics at the tripartite enclosures in Ross County, Ohio give us some indication of the effort that went into building those massive complexes, the integrity of those earthworks has been severely diminished from decades of agricultural activity. Thus, other large Middle Woodland earthworks provide a more accurate comparison to Serpent Mound: namely, the Newark Octagon. The Octagon enclosure at Newark is connected to a large circle (Observatory Circle) by means of two parallel earthen walls. The circle measures approximately 317 m in diameter, while the Octagon is about 445 m across and encompasses an area of approximately 16.5 hectares. The walls of both enclosures are approximately 9 m wide and 1.8 to 2 m tall. A newly created photogrammetry model of the Newark Octagon complex by Davis provides an excellent topographic view of the earthworks. By sheer coincidence, Davis found that one section of the Octagon's embankments is slightly larger than the

serpent's volume of 1,202 m^3. Using the same techniques described above to generate the Serpent Mound volume, computations of one segment of the Octagon from the photogrammetry data produces a volume of 1,414 m^3 (see Figure 7.11).

Using that one section of the Octagon to estimate the total volume for the entire enclosure, it appears that the Octagon, the Observatory Circle, and their associated mounds combined have a volume roughly 20 times larger than that of Serpent Mound. Remarkably, the Octagon-Observatory Circle complex is only part of the larger Newark earthwork system (see Figure 7.12). The earthworks at Newark are some of the largest earthen wall enclosure sites in the world, and along with the other large earthworks sites in Ohio, they represent a dramatic shift in earthwork construction strategy from the Early Woodland period to the Middle Woodland period.

A final construction distinction between Early Woodland and Middle Woodland earthwork building involves wooden architecture. While approximately one-third of Early Woodland mounds cover the foundations of wooden structures (Hays 1994), all Middle Woodland mounds (excluding those in enclosure gateways) cover wooden building remains. Many of

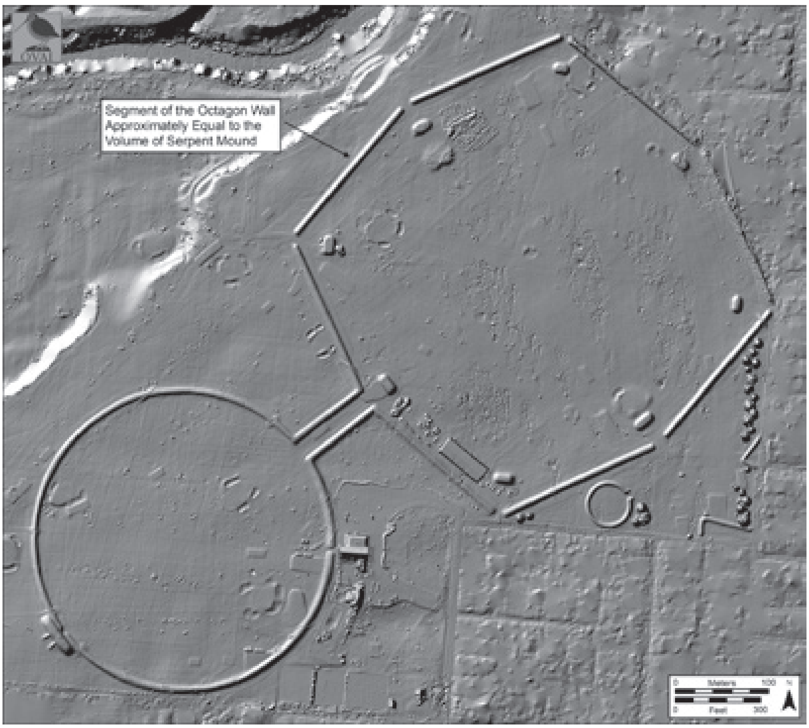

Figure 7.11 The Middle Woodland Octagon and associated Observatory Circle located in Newark, Ohio. One section of the Octagon contains the equivalent volume of Serpent Mound

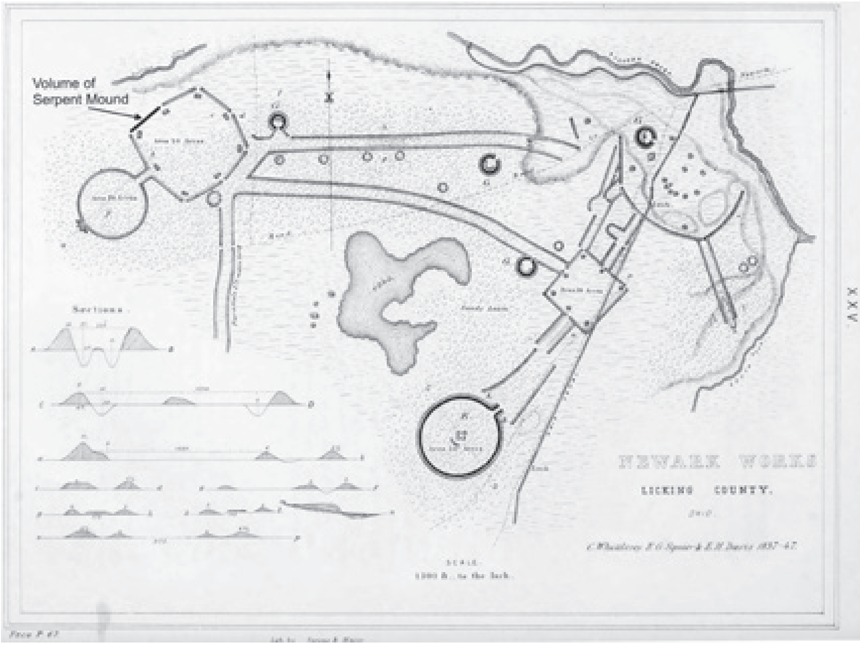

Figure 7.12 The Octagon and Observatory Circle are only part of a larger complex of geometric enclosures that once occupied the Newark area. The size and effort of Serpent Mound pales in comparison to the Newark complex of enclosures

these structures were quite large and appear to have been deconstructed prior to the building of the mound (e.g. Greber 1983, 2015; Mills 1916, 1922; Moorehead 1922). These and other buildings (e.g. Kanter et al. 2015) were so large that their construction and deconstruction probably equaled a significant percentage of the effort needed to construct the earthen walls at some sites. Many of the Middle Woodland earthworks sites also appear to contain relatively small ceremonial spaces within the larger complex, such as the numerous wooden post circles recently found at the Steel Group (Burks 2017), the enormous post circles at the Hopeton Works and Hopewell Mound Group (Burks 2013; Ruby et al. 2017), and the Moorehead Circle found within Fort Ancient (Burks 2014; Riordan 2015). Taken together, the construction effort at Middle Woodland ceremonial centers far exceeds that of any Early Woodland earthen construction.

The Middle Woodland mound-builders seem to have been able to complete these massive earthwork constructions by both increasing the amount of time spent on the construction and increasing the area from which to draw the labor pool. During the Middle Woodland, annual participation may have increased from, say, five days per year to perhaps ten days, and

the recruitment of the number of participating hamlets may have increased as well (Bernardini 2004). An increase in the size of the workforce, and its wider geographic range, is supported by the massive influx of nonlocal material goods found at many large Middle Woodland ceremonial centers (e.g. Lynott 2014; Mills 1916, 1922; Moorehead 1922; Seeman 1979; Willoughby 1922). Some scholars have even suggested that extra-regional populations made pilgrimages to these large ceremonial centers (Greber 1996; Lepper 2006; Vickery 1996). If future research confirms this, these pilgrims more than likely participated in the construction effort.

Conclusion

The first settled hamlet communities in the Ohio Valley were composed of relatively few people – perhaps 2 or 3 families representing 12 or so people. These hamlets were rather dispersed across the landscape since their economy was in part based on hunting and gathering, an economic strategy that required considerable space between communities to be most effective. Given that dispersed form of settlement, it is easy at first glance to assume limited organizational capacities for each of these small hamlet-based communities.

The architectural energetic analysis of Serpent Mound counters this assumption. Our results indicate that small and dispersed communities could and did collectively unify for a single purpose – in this case building an earthen icon on the landscape – and accomplish far more than any single hamlet could have done alone. Serpent Mound reflects the ability for dozens of small hunter-gatherer/horticultural communities to aggregate and work together on a collective project with a singular unifying purpose.

Further, this analysis indicates that small communities of dispersed hamlets were capable of organizing for the purpose of building a communal structure, drawing participants from a distance to do so. The implication is that dispersed communities need to create and maintain bonds that unify, bonds that remind people of their shared history in times of plenty as well as times of scarcity. These societal bonds were realized and materialized by projects such as Serpent Mound. In this way, tribal societies share the potential for and demonstration of monumental collective effort with more complex societies, scaled appropriately to their sociocultural system. With additional energetic investigations of features constructed by non-state societies, we can continue to better articulate sociocultural similarity, difference, and change.

Lastly, as technologies like UAV-based photogrammetry and magnetometry continue to develop in archaeology, a more accurate picture of the past begins to emerge. When considering these large earthwork construction sites using energetics, small errors in shape interpretations can lead to large errors in final estimates. Photogrammetry eliminates the need for interpreting a shape and reduces the error in final estimates. With the new, accurate volume estimate for Serpent Mound, we have an accurate labor estimate

of its construction and a much more accurate picture of the past with the potential to correlate the conclusions reached here with other investigations of non-state society architectural energetics.

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8 The energetics of earthen landscape modification

An assessment of an emerging Mississippian polity

Cameron H. Lacquement

Introduction

Elite control over labor is an important factor in the sociopolitical organization of emergent complex societies. Energetics studies of monumental architecture are of benefit to archaeological inquiry because they can provide a method of examining how labor and material resources were organized and controlled by ruling elites. Thus architectural energetics is a tool that can be used in modeling social differentiation as it was reflected in the amount of energy deployed in the building of various monumental forms. "Architecture, by virtue of its capacity to absorb relatively large amounts of energy during production, can hypothetically reflect a significant range of organizational behaviors requisite for such construction, an important index of cultural complexity" (Abrams 1989, 53).

Currently, there are contrasting sets of theory as to how surplus labor and material resources were organized within emergent complex societies. One framework suggests that monuments are indexes of elite power in societies possessing centralized hierarchical authority, and that elite power was symbolically reinforced through "conspicuous consumption" of energy as human labor (Trigger 1990). Under this "power perspective," monuments are viewed as testaments to the ability of a centralized authority in a socially stratified situation, in which the political elites use their coercive power to exert control over surplus food production, to organize material resources, and to amass large quantities of labor for the construction of non-utilitarian projects (Price 1978; Renfrew 1983; Steponaitis 1978; Trigger 1990). A contrasting perspective views the allocation of labor and resources for monument building in emerging societies as "heterarchical." That is, the decision-making processes are not *exclusively* hierarchical or based on fixed social rank (Blanton et al. 1996; Brown 2006; Kelly 2006). Heterarchical arrangements are composed of social networks that are either unranked or likely to be ranked in different ways, creating horizontal positions of power (Crumley 1995). Archaeologists advocating heterarchy argue that to portray monuments as symbols of elite power exercised over a subordinate population is too limiting and ignores the roles of horizontal and communal

relationships in constructing accurate narratives of prehistoric societies. The heterarchical framework, although not entirely exclusive from a hierarchical one as they can both exist within society, is a reaction against the "inclination to seek some hierarchical control behind every engineered construction, a coercive power behind every substantial pile of earth or stack of stone, and an economic pull behind every accumulation of exotic goods" (Brown 2006, 198).

These two competing interpretations of emergent complex societies are embedded in current theories of Mississippian (c. 1050–1550 CE) sociopolitical organization (see Blitz and Livingood 2004; King 2006; Knight 1998; Steponaitis 1978; Sullivan 2006; Welch and Butler 2006). Specifically in the case of Mississippian mounds, mound size has been viewed as a direct reflection of the organizational capabilities of a powerful sociopolitical hierarchy. In contrast, others have argued that the labor involved in Mississippian mound construction did not necessarily require powerful leadership structures, as it was not as burdensome on the general population as is commonly believed. If the surplus was not organized by elites exercising their power over their subordinates, it is reasonable to conclude that labor and material resources for mound construction were organized at a kin-based level.

Both top-down political economy perspectives and the recruitment of labor by segmentary kin groups have been previously suggested for the Moundville chiefdom, a Mississippian polity in west-central Alabama. Steponaitis (1978) argued for the existence of a strong hierarchical political leadership at Moundville based on the size and location of outlying single mound centers. The efficient spacing of these single mound centers accompanied by the increasing size of mounds as the distance between the secondary centers and the Moundville polity increased implied the allocation of labor as possible tribute. Others have argued for a strong political hierarchy at Moundville based on food tribute, prestige goods, and the distribution of material resources (Scarry and Steponaitis 1997; Welch 1996). Based on the elite control over tribute and material resources at Moundville, Welch (1996) suggests that mounds may have belonged to high ranking members of a paramount chief's own kin group, as opposed to the possibility suggested by Knight (1998) that mounds belonged to ranked kin-based social groups. Knight proposed that Moundville's layout represents a diagrammatic ceremonial center, and that the plaza periphery mounds were devices for stabilizing societal relationships between ranked kin groups. This would imply that mound construction was organized and executed by segmentary kin groups, not the overseeing elites.

In this chapter, the amount of human energy employed in earthen monumental construction at Moundville, Alabama is quantified in order to address the organizational variability of the control of surplus labor and material resources in an emerging complex society. To help reconstruct the scale of sociopolitical differentiation invested in mound building, I create an assessment that calculates the energy necessary to excavate, transport,

and compact mound and plaza soils. Based on the energy expended for each monumental form, I address the manner in which power over surplus labor and material resources may have been controlled in a Mississippian polity. Put simply, I attempt to answer the question of whether the Moundville landscape could have been constructed using labor entirely recruited within a segmentary system such as kin groups or in contrast whether the scale of monument building required some form of political control whose power transcended the level of segmentary kin groups.

Research setting: Moundville, Alabama

Moundville is a large Mississippian mound complex located on the Black Warrior River in west-central Alabama. The landscape is composed of at least 32 earthen mounds stretching over 75 hectares (185 acres) on a high level terrace overlooking the Black Warrior River. The majority of mounds are arranged in a quadrilateral fashion around the oddly orientated Mound A and a large central plaza, with the Black Warrior River marking the northern boundary of the site (see Figure 8.1). All of the mounds on the periphery of the plaza are aligned with the cardinal directions, with the

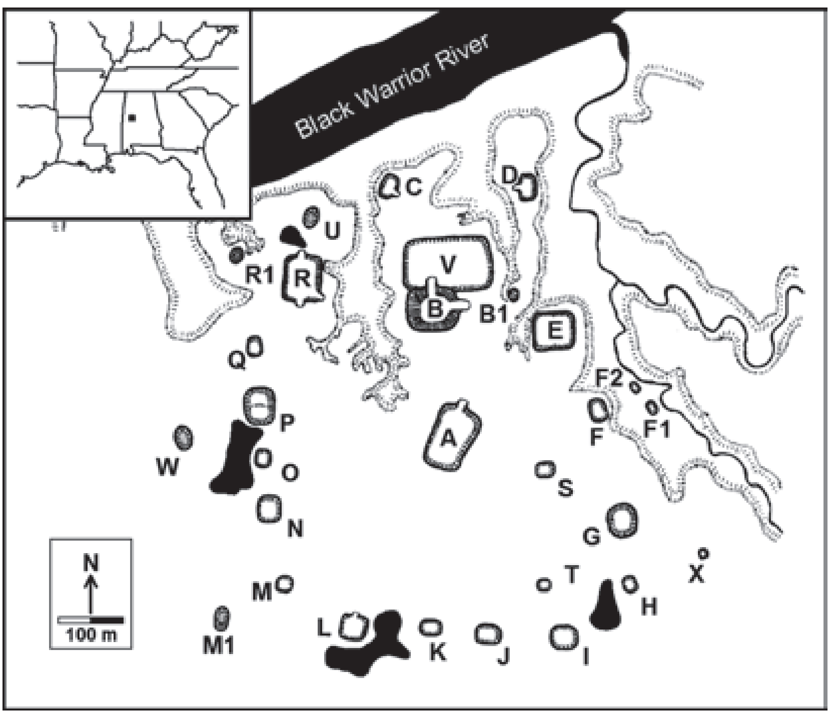

Figure 8.1 Moundville sketch map showing 28 mounds, current ravines, and four lakes (west of Mounds H, K, O, and north of Mound R)

longer sides of these mounds facing the plaza. The mounds range from less than a meter in height to more than 17 m, the average mound height being roughly 5 m.

The spatial arrangement of the mounds at Moundville is more orderly and methodical than the layout at many other Mississippian mound centers. A bilateral symmetry is believed to exist between the east and west halves of the site, creating an imperfect mirror image (Knight 1998; Peebles 1971, 1974, 1983). The bisecting north-south line runs through Mound B, and a portion of Mound V on the northern end continues southward through Mound A and runs between Mounds J and K at the southern margin of the plaza. The 15 largest mounds arranged around the plaza alternate between large earthworks without burials and small mounds containing burials. In addition, certain mounds appear to have a parallel counterpart in size and use across the plaza in relation to the bilateral symmetry of the site.

Accompanying the east-west symmetry, there is a north to south trend in the elaborateness of burials and the size of mounds. The most elaborate burials and grave goods occur at the northern end of the site and generally decrease in elaborateness as one moves south (Knight 1998; Peebles 1974). The size of the plaza periphery mounds without burials also decreases in a southward direction on either side of Mound B. The plaza periphery mounds without burials are larger monuments than the smaller plaza periphery mounds containing burials.

The layout of Moundville is believed to represent a sociogram, a physical design that inscribes the ranking of corporate segments within the community permanently upon the landscape (Knight 1998). It is hypothesized that the diagrammatic nature of the landscape was intentionally created to emphasize fixed social distinctions between kin groups, which determined the size and placement of mounds around the plaza. The larger mounds are believed to represent the higher ranking groups while the smaller mounds are believed to represent the segments of lesser rank. In addition, each large plaza periphery mound without burials has at least one corresponding smaller mound with burials, which supports the idea that pairs of mounds were associated with specific kin segments.

The Moundville polity is believed to encompass a 5 km wide portion of Black Warrior River valley, extending northward from the Moundville site approximately 25 km and approximately 15–35 km southward from the Moundville site (Bozeman 1981; Peebles 1987; Steponaitis 1983; Welch 1990). The occupation of the polity is divided into four phases: Moundville I (1120–1260 CE), Moundville II (1260–1400 CE), Moundville III (1400–1520 CE), and Moundville IV (1520–1650 CE). The paramount center was first inhabited during the onset of the Moundville I phase (1120–1260 CE). The Late Moundville I and Early Moundville II subphases represent the climax of physical modification to the site. The majority of the mounds and plaza alterations were constructed in a relatively short time, probably over little more than a century (1250–1350 CE),

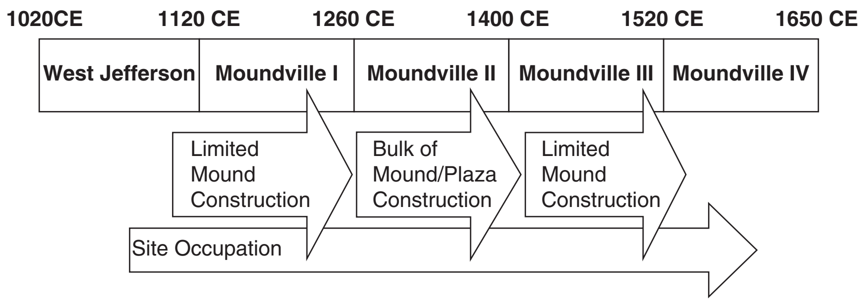

Figure 8.2 Moundville timeline

and declined continuously until the site was abandoned. Only Mounds P, B, and E, the largest residential mounds located on the north side of the arrangement, were still in use by the beginning of the Moundville III phase (1400–1520 CE). The occupation of these three mounds lasted until approximately 1550 CE, although there were no earthen constructions or modifications made at the site after 1450 CE (see Figure 8.2). The simultaneous construction of the major mounds early in the site's history also indicates a deliberate community plan, not a landscape of mounds added gradually over time (Knight 1998). The peak resident population probably was relatively small, with around 1,000 people (Steponaitis 1998), many of whom might have vacated the ceremonial center prior to the time of peak mound construction (Wilson 2008).

Energetics assessment

The labor expended in building Moundville's monumental landscape is conceived for this study as having three components: energy of excavation, energy of transportation, and energy of compaction (see Figure 8.3). The unit of measure for human energy expenditure for this assessment will be expressed in kilojoules (kJ) as opposed to person-hours (Abrams and McCurdy, Chapter 1). One clear benefit of changing the unit of measure from person-hours to kilojoules is to enable archaeologists to adopt methods and data from other disciplines such as physics, engineering, physiology, human biology, kinesiology, ergonomics, and military and sports medicine. These disciplines have studied modern-day energy expenditures extensively for some of the assessment of work projects in some ways comparable to prehistoric projects, such as energy needed to transport a weight over a given distance, to excavate soil or rock using various instruments, or even to create an engraved design upon a large piece of stone (e.g. Abe et al. 2008; ECAFE 1957; Frisancho 1993; James and Schofield 1990; Knapik et al. 2004; Malville et al. 2001). Results of these cognate studies are expressed

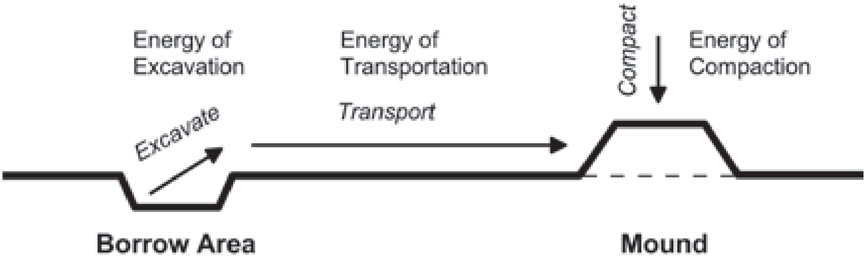

Figure 8.3 The three energy components as visualized for this study

in kilojoules (kJ), kilocalories (kcal), maximum oxygen consumption (VO_2 max), or other comparable units such as metabolic equivalent (MET), physical activity ratio (PAR), or integrated energy indices (IEI). Using density or weight of building materials instead of volume enables the archaeologist to calculate an energetics assessment in widely comparable units ultimately allowing for a consolidation of the two types of studies in which human physiological data may be directly applied to archaeological problems.

To create an energetics assessment of the Moundville landscape, three factors had to be considered. First, the volume of all culturally positioned soils are accurately accounted for including the soil needed to create the mounds as well as any soil that may have been used to level or flatten the plaza (see Table 8.1). The volume of the 32 Moundville mounds was last calculated in 1936 by geologist Walter B. Jones, using an unknown method of estimation – presumably a geometric equation. Using both early and more recent topographic and photogrammetric data, the volume of each mound was recalculated using computer software (Lacquement 2010). Additionally, evidence suggests that large amounts of soil extending outward from the plaza side of the mounds was laid down in order to level the outer edges of the plaza (Knight 2010; Knight and Steponaitis 1998; Lacquement 2009). This plaza-leveling construction would have required similar organization and energy to accomplish and thus is included in the energetics assessment. Auger testing and excavations are employed in this study to test for plaza leveling and to determine the depth and horizontal extent of these soils. The volume of the plaza fill is added to the newly calculated total volume of the mounds to provide a more accurate volumetric estimate of the culturally placed soil at the site.

Second, the distance from mound and plaza fills to their probable extraction locations is estimated based on a comparison of soil samples taken from around the site (see Table 8.1). Unlike other large Mississippian landscapes, Moundville does not possess numerous large borrow pits. There are four artificial water-filled formations presently at the site referred to as “lakes,” but there has been some debate as to whether these are legitimate borrow pits or instead were created for ambience to attract park goers while dealing

Table 8.1 Volume estimates and probable distance from soil extraction source to center of the earthwork for plaza periphery mounds and plaza fill

Mound/plaza	*Current best estimate (m^3)*	*Distance (m)*
A	30,150	160
B	49,530	110
C	5,080	25
D	3,880	45
E	10,820	50
F	2,790	50
G	6,730	115
H	675	190
I	2,690	250
J	2,570	145
K	1,855	60
L	4,420	25
M	590	125
N	3,295	300
O	1,220	230
P	15,880	150
Q	3,210	50
R	21,820	70
S	515	180
T	705	240
V	22,460	95
Plaza F	2,545	75
Plaza G	5,480	110
Plaza N and O	6,540	250
Plaza J	580	135

with drainage issues during park restoration projects in the late 1930s. The largest genuine borrow pit has a volume that only accounts for about 7% of the recalculated volume estimate for the site. Soil for most mounds and plaza modifications therefore probably came from the closest ravine on the north side of the site. These large, deep ravines are not typical of similar geological terrace formations along the Black River Valley. It is possible that they were originally much smaller and were artificially increased in size due to the borrowing of soil for landscape alteration. On the other hand, it is possible that there were several small borrow pits that were refilled by plowing and sedimentation from erosion.

Third, in order to calculate the energy needed for mound construction, the mass and density of each earthwork are estimated in addition to its volume. Geotechnical engineering methods, such as the sand-cone test (ASTM D1556 2015) and the Proctor compaction test (ASTM D698-12e2 2012), are applied to the landscape in order to calculate the density, mass, and compaction of the earthworks. The density of four plaza units possessing evidence of artificial plaza surface was measured, as well as the density from

the outermost construction stages of two mounds, Mounds R and V. The density calculated from the sand-cone test, and the newly estimated volume of the mounds and plaza fill allowed the mass of each earthwork to be calculated, using the formula: volume × density = mass.

Energy of excavation

Based on previous experimental studies in soil excavation (Erasmus 1965; Hammerstedt 2005), the total volume of the soil of each mound is divided by the amount of time for a given unit of measure. This measurement, in the form of a volume of excavated soil per hour (v/hr), is converted to energy expended per given mass (kJ/kg). The average energy expenditure for one hour of excavating ranges between 1,200 and 2,000 kJ (Ainsworth et al. 1993; James and Schofield 1990). Using Hammerstedt's (2005) value of 0.29 m^3 of excavated soil per hour multiplied by the estimated average natural density of soils at Moundville, 1,442 kg/m^3 (90 lb/ft^3), the mass of soil excavated per hour is 418 kg (921.5 lb). If it takes the average human a minimum of 1,200 kJ of energy to excavate soil for one hour, then that amount of energy is expended in excavating 418 kg of soil or 2.87 kJ per kg. The mass of a mound multiplied by the energy to excavate a given mass (1,200 kJ per 418 kg), results in an estimate of the energy of excavation for that mound, as measured in kJ. Using Mound R as an example, the mass of the earthwork (40 million kg) is multiplied by 2.87 kJ per kg which equates to the energy of excavation at 115.7 million kJ.

Energy of transportation

In order to calculate transportation energy, two additional measurements are needed: the mass of an average load and the distance between the mound and the excavation source. Some archaeologists (Ford and Webb 1959; Fowke 1902; Porter 1974; Shetrone 2004) have reported on the possible sizes of basket loads in the archaeological record. Estimates ranged from 7.3 to 22.7 kg (16–50 lb). For this study, 11 kg (26 lb) per basket load is used as the average load transported.

With the distances from the center of earthworks to the nearest borrow areas estimated (Lacquement 2009), the distance for each earthwork is multiplied by the energy to carry an 11 kg load over that distance, and then walk back the same distance unburdened. The average energy expended to carry an 11–16 kg load at an unspecified walking speed is 1,675 kJ per hour (James and Schofield 1990, 135). Assuming that the laborers are walking at a speed comparable to Erasmus' (1965) workers, that is, slightly less than 4.8 km/h (3 mph), a transport distance of 4,828 m (three miles) would take approximately 1,675 kJ of energy (or 0.35 kJ/m) for the transportation of one basket load. The average energy of walking at 4–5 km/h (2.5–3.1 mph) without carrying anything over the same distance is estimated

to be approximately 1,072 kJ (or 0.22 kJ/m) (James and Schofield 1990, 135). For this assessment, the distance from the center of an earthwork to the nearest borrow area is multiplied by these values. The products of these two calculations (energy of a single trip with a load and energy of a single trip without) are added together to produce the energy needed for a single round trip during the construction of an earthwork. Then, the mass of each earthwork is divided by the estimated average load carried, 11 kg, which results in the number of round trips. The energy for a single round trip is multiplied by the number of trips. For example, the center of Mound R is approximately 70 m from the nearest soil source. This distance is multiplied by 0.35 kJ/m (energy required to carry load from the source to the mound) and 0.22 kJ/m (energy needed to walk from the mound back to the soil source). Then the products of each (25 kJ and 15 kJ) are added together for the total transportation energy needed to make one round trip, 40 kJ. The mass of Mound R, 40.3 million kg, is divided by 11 kg, the estimated average basket load weight, to determine the number of times the trip was made. In this case, 3.66 million round trips would be needed. The energy per trip (40 kJ) is multiplied by the number of round trips, resulting in the total transportation energy, 146 million kJ.

It should be noted that the energy expended in carrying a load can be greatly affected by the manner in which the load is carried. There are numerous methods for carrying a load, including using a head basket, head strap (tumpline), chest strap, satchel, bag, or shoulder yoke. Prehistoric mound builders may have even transported soil using a bucket brigade method, in which the basket load is passed from one stationary person to another. The method of transportation consistent with ethnohistorical accounts of Native southeast historic tribes involves baskets carried on the back employing either tumplines (head straps) or chest strap supports (see Bushnell 1909; Hudson 1976; Hvidt 1980). For this reason, in this study energy calculations are based on the transporter carrying a load on their back.

Energy of compaction

Little emphasis has been paid to the amount of energy needed to compact earthen monuments (for examples see Lacquement 2009; Xie et al. 2015; Xie, Chapter 1). Although this measurement is rarely included in energetic assessments of earthen mounds, it was probably a fairly labor consuming activity and crucial for the structural integrity of the earthwork. Density of mound soil would have decreased during the extraction process, making it structurally unsound for earthen construction without compaction. Yet, like transportation, there are a number of different ways compaction can be accomplished by native inhabitants.

The amount of compaction energy is measured by first recording the density of an earthwork using the sand-cone test to calculate the density of the soil in an existing structure. The soil removed in the test, which is replaced

with standardized sand in the field, is compacted in the laboratory using a standardized device to compact the soil until the density of the Proctor compaction test produces a sample the same density as found in the field. The result expresses how much energy is needed for a sample of soil from an earthwork to be compacted to match the density measured in situ with the sand-cone test. It should be noted that compaction energy in this form does not represent human energy but instead raw kinetic energy of compaction. To achieve a specific compaction level, a person has to drop a weight, such as a log pestle, rock, or their body (jumping, marching, or stomping) from a certain height. The more highly compacted the earthwork, the more human energy that must have been invested. Clearly, additional research is needed to strengthen the relationship between the mound compaction and the amount of human energy expended. In the meantime, for this research, in order to calculate the amount of human energy expended in soil compaction, the mass of the earthwork will be multiplied by the energy expended in marching on level ground, essentially using a constant value for what was certainly a variable (James and Schofield 1990, 134). It will be assumed that the method of compaction employed by the prehistoric inhabitants of the site was walking over the soil repeatedly with a stomping motion. The amount of energy expended in marching, 1,440 kJ per hour, is multiplied by the mass of each earthwork and divided by 1,000 kg (2,005 lb) (or 1.44 kJ/kg), as it will be assumed that one person could compact 1,000 kg of soil per hour. There is no research to support this assertion, but it seems reasonable to assume that one laborer could compact almost twice as much soil as one laborer could excavate in the same amount of time. In the case of Mound R, the mass, 40.3 million kg, is multiplied by 1.44 kJ/kg to estimate the amount of human compaction energy to be 58 million kJ.

Results

Using these measures, the earthen landscape at Moundville (32 mounds and 4 plaza additions) is estimated to have required approximately 3.8 billion kJ (2.83 trillion ft/lb) of human energy to construct. This estimate includes the amount of energy to excavate, transport, and compact mound and plaza soils over the lifetime of the site. In terms of the energy invested per task, it appears that transportation energy was slightly more labor intensive than the energy needed to excavate or to compact. The energy of transportation (2.2 billion kJ) accounts for almost 58% of the total energy expenditure. The energy of excavation (1 billion kJ) totals 28% while the energy of compaction (530 million kJ) totals 14%. Depending upon the distance to the extraction source, transportation energy did not always exceed the energy of excavation. In the majority of cases, the energy to excavate exceeds the energy to transport mound soils, except when the transport distance is greater than 50 m. The energy of excavation of a mound is reasonably consistent with its mass, whereas the energy to transport can be altered

significantly depending upon the distance to the nearest source. In other words, substantial amounts of transportation energy could be conserved by careful planning and positioning of the borrow pit.

Hypothetical scenarios of the working population

The amount of energy invested in monumental constructions at the site (3.8 billion kJ) does not take into account either the number of people participating or the length of time spent on the construction. Those inhabitants at Moundville participating in mound and plaza constructions, herein referred to as laborers, could have consisted of small kin-organized work groups or larger publicly sanctioned construction teams drawn from the entire polity. To examine the number of laborers for a given construction project and explore the organization of labor, the measure is converted into person-days by dividing the total energy of construction by hypothetical estimates of the population and the amount of energy each laborer expended per day. The number of laborers cannot be determined archaeologically, but hypothetical scenarios can be developed that are suggestive of the work that could be accomplished by varying numbers of participants. The result is a rough calculation of the amount of time it would have taken some given number of laborers to complete construction at the site. If the resulting time estimate is within the range of the known construction history of the site, it may be considered a reasonable scenario.

Although Moundville was occupied to various extents from 1050 to 1650 CE, it is believed that the majority of mound construction took place over a 200 year period, from roughly 1250 CE to around 1450 CE (Knight and Steponaitis 1998) (see Figure 8.2). There was no meaningful construction after 1450 CE. Moreover, Knight (2010) claims that the vast majority of mound building took place over only 100 years, c. 1250–1350 CE. Also, population estimates for creating reasonable scenarios are based on the amount of labor contributed per person during a full year. Mound construction however was probably not a yearly activity. On the contrary, based on the stratigraphic evidence of mound construction it appears that large construction stages were added to earthworks at rather lengthy intervals (Anderson 1994). The time span of a site is important to know for creating realistic scenarios of the number of laborers participating in mound construction.

In considering the number of possible laborers, one must also examine population estimates for the site. Steponaitis (1998) has argued that roughly around 1,000–1,700 people lived at the center during the peak occupation in the Moundville I phase (1120–1260 CE), while Peebles (1987) estimates that 10,000 more lived in the hinterlands. Muller (1997) estimates that roughly 1/5 of any given Mississippian population worked on mound construction, basically one person per household of five. Muller (1997) does not specify the source of the 1/5 ratio; presumably it is meant to represent one worker per household. Scarry (1998) uses the range of Moundville house floor sizes

(Peebles 1978) and Naroll's (1962) formula for calculating household size creating an estimate of 1.3–3.4 people per house. As this is low compared to ethnohistorical sources (Hann 1988, 166; Swanton 1911, 43), Scarry (1998; also see Steponaitis 1998) assumes 5–8 people per household in the Black Warrior River valley. Other ratios that have been used include 1:2 by Bernardini (2004) who assumes that half of the population was capable of participating in mound construction. R.L. Kelly's (1995) ethnographic study of hunting-gathering bands assumes a ratio of 1:3. However, for the sake of the example at hand, three approximations for the population from which the laborers were drawn (1,250, 5,000, and 10,000) are divided by five, yielding 250, 1,000, and 2,000 laborers. Based on current estimates, the first figure might include the Moundville I phase population resident at the site while the last two would certainly involve large contributions from some or all of the hinterland populations as well.

The total amount of energy implicated in earthwork construction (3.8 billion kJ) can be divided by the product of: 1) 12,500 kJ per day, the minimum amount of energy of a human engaged in heavy labor (Kroemer and Grandjean 1997, 251–252) multiplied by; 2) the estimated number of workers – 250, 1,000, or 2,000; and 3) the estimated number of days per year for those laborers participating in mound building. For example, the energy of construction of the site (3.8 billion kJ) divided by the product of 12,500 kJ per person-day and 250 laborers (drawn from a population of 1,250) working an average of ten days per year is 122 years. Given that the Moundville landscape was constructed during a time span of 100 to 200 years, this estimate of people and time seems to be a reasonable scenario. The reader should note that simply dividing the total construction energy by the product of energy per day and estimated number of laborers will yield the total number of workdays, whereas the number of workdays per year must also be assumed. In reference to the example above, the concept of workdays per year is factored in to give the reader a more tangible idea of the amount of labor that would have been required over the 100–200 year duration of construction. Construction stages for an average mound were highly episodic, not annual (Anderson 1994), and there could have been several years in which there was no construction. However, these energetic estimates provide a range of probable scenarios for constructing the landscape based on estimates of the size of labor pool and days of labor, which can be corroborated by ethnographic comparison.

Using estimates of energetic expenditure, Moundville would have been constructed in approximately 300–1200 total working days assuming the average year required three to ten days of labor and the labor pool ranged between 250 and 1,000 people. The number of laborers would probably have peaked around 1,000. Steponaitis (1998) estimates the peak population at Moundville to have occurred during Moundville I (1120–1260 CE) and Knight (2010) estimates that mound construction around the plaza began no earlier than 1250 CE and slowed down by 1350 CE, which leaves

very little overlap between a peak residential population and mound construction (also see Wilson 2008). One may reasonably conclude that laborers for mound constructions came from the hinterlands and not merely from Moundville's residential population.

When energy for earthen monumental construction is calculated in terms of the three components of construction energy, it appears that earthen constructions were slightly more labor intensive than some current scenarios suggest. For example, Muller (1997, 274) states that 250 laborers (a fifth of a population of 1,250) working four days a year could have created Moundville in 160 years (640 total workdays) assuming that a single person could excavate and transport 1.25 m^3 of soil in one day. Assuming a density of 1,442 kg/m^3, the mass of 1.25 m^3 is 1,803 kg (3,975 lb) of soil that would need to be moved by a single worker per day. Using the estimates calculated for this study, 250 laborers at Moundville working more than 1,120 total workdays, or seven days a year, could have created the site in approximately 160 years. The difference between my estimates and Muller's equates to almost twice as much labor, yet both work projections conclude that only a fairly few number of workdays were required to construct the landscape and are not excessive or ethnographically unrealistic based on expectations of an emerging complex society.

Individual mound stages

The Moundville landscape, like other Mississippian landscapes, was not created continuously over time. Instead, individual mounds were built in discrete stages, with long intervals in between (Knight 2010; also see Anderson 1994). Some of these mound stages were very large and would have required sizeable work crews. Some were relatively small. The manner in which results are presented, in days of labor per year, probably do not reflect a realistic timing in which these landscapes were constructed. It is these mound stages that are the true "packages" or units of mound construction and much more attention should be devoted to the labor needed for each of these smaller quantities.

To get a better idea of the organization of labor required for individual mound stages, reasonable hypothetical scenarios were created for three mound stages at Moundville: 1) Stage III of Mound A, 2) Stage II of Mound F, and 3) Stage I of Mound R. These three stages represent the largest construction stage in each of these three mounds. Using volumes for these stages estimated from mound excavation records and coring results (Gage 2000; Gage and Jones 2001; Knight 2010), the total amount of construction energy is calculated in the same manner as described for entire earthworks.

Stage III of Mound A is approximately 10,850 m^3, the largest of the three mound stages examined for this study. The volume of this stage was loosely calculated using the ratio of the height of the building episode to the height of the entire mound assuming symmetry. Knight (2010) reported this

building stage to be roughly 2.38 m thick. As Mound A is currently 6.7 m high, the height of the stage was divided by the height of the mound and then multiplied by the total mound volume. The volume of Stage II of Mound F was calculated from a profile drawing (Knight 2010) in a similar manner as Stage III of Mound A; a ratio of the height of the stage to the height of the mound. The volume of Stage I of Mound R was previously calculated by Gage (2000). However, his final volume estimate for the mound, calculated using multiple geometry solids (see Lacquement 2010), was slightly larger than the estimate obtained using the gridding method. Thus, to estimate a more precise volume of the mound stage, the gridding method volume estimate (21,820 m^3) was divided by Gage's (2000) estimate of 30,700 m^3. This ratio, 0.71, was multiplied by Gage's estimate of Stage I, 9,900 m^3, resulting in a new estimate of the volume of Stage I proportional to the overall volume obtained using the gridding method, 7,030 m^3.

With the volume, mass, and various energies of construction of these three construction stages calculated (see Table 8.2), the total energy of construction for each stage can be divided by estimates of the number of laborers multiplied by the estimated number of kJ expended per day. The result would be the total number of workdays invested in each construction stage. If it is true that the construction stages of the smaller plaza periphery mounds were built using kin-based labor, then they should have required smaller and perhaps more diverse groups of people (consisting of various family members as opposed to specialized work crews) than the larger central mounds, A, B, and V. Fifty, 250, and 1,000 laborers were drawn from total populations of 250, 1,000, and 5,000, respectively. A single kin group might have mustered 50 laborers and perhaps even 250 (if they were 1,250 strong), but 1,000 (drawn from a population of 5,000) is unrealistic for one kin group alone and would suggest a more centrally motivated political structure.

For Mound A, 50 laborers could have constructed stage III in 475 days, whereas 250 laborers could have constructed the stage in 95 days (see Table 8.3). Both of these scenarios seem unrealistic, considering that the stage was probably constructed as one continuous building episode. This amount of time is also much longer than the typical estimates for the amount of time invested in monumental construction, except by state-level organizations (Bernardini 2004; Erasmus 1965). The most reasonable scenario for this stage is approximately 1,000 laborers working for 24 days. As for Mound F, 50 laborers could have constructed Stage II in approximately 20 days, whereas 250 laborers could have constructed it in four days, and 1,000 laborers could have completed it in little more than one day. Using the same three figures for number of laborers as the other two construction stages, it would have taken 50 laborers 169 days to complete the first stage of Mound R. On the other hand, it would have taken 250 laborers 34 days or 1,000 laborers eight days to complete Stage I. 250 laborers working 34 days is a comparable time frame to those that are

Table 8.2 Energy of construction for three mound stages at Moundville

Mound stage	*Volume (m^3)*	*Mass (kg)*	*Energy of excavation (kJ)*	*Energy of transportation (kJ)*	*Energy of compaction (kJ)*	*Total energy of construction (kJ)*
Mound A Stage III	10,850	20,100,000	57,700,000	168,100,000	28,900,000	254,700,000
Mound F Stage II	1,005	1,900,000	5,500,000	4,800,000	2,700,000	13,000,000
Mound R Stage I	7,030	13,000,000	37,300,000	47,300,000	18,700,000	103,300,000

Table 8.3 Number of possible construction days based on the estimated number of laborers

Number of days projected			
Number of laborers	*Mound A*	*Mound F*	*Mound R*
50	475	20	169
250	95	4	34
1,000	24	>1	8

reasonable for the other two mound stages just discussed. It is possible that 250 laborers could have been drawn from a single kin group, however, 1,250 people might be pushing the upper limit for one kin group based on population estimates.

Discussion

Energetics assessments provide a range of possible scenarios, the most accurate of which can be confirmed based on the expectations for labor and workdays in an emerging complex society. Granted, several different scenarios can be created using a single amount of energy. The Moundville landscape could have been constructed by 50 laborers working an average 50 days per year or 500 laborers working an average of five days per year to complete construction in the designated time frame of approximately 100 years. Ethnographic information for emergent complex societies estimates that communal labor projects typically required between 25–50 person-days per year (Bernardini 2004, 344–345; Erasmus 1965, 280). However, the actual number of days per year could be highly variable depending on the political motivations fueling construction (see Kolb 1991).

Based on ethnographic comparisons for the amount of time invested in construction for emerging complex society, the results indicate that smaller mound stages, like the second stage of Mound F, could have easily been constructed by a number of laborers amassed from a single very small kin group. Mound R, which is the largest plaza periphery mound other than those of the central axis of the site, could have also been created with labor amassed from an average-to-large sized kin group. The results suggest that all mounds on the plaza periphery other than the mounds on the central axis could have been constructed by kin-based segments. However, Stage III of Mound A would have required at least 1,000 laborers in order to complete the project in the designated amount of time, which probably exceeded the number of laborers that could have been allocated from an average sized kin group. Therefore, labor must have been organized above the kin-based level. Based on labor estimates for Mound A, it is reasonable to assume that the larger Mound B, and slightly smaller Mound V could not have been constructed using kin-based labor alone.

In conclusion, the mounds on the plaza periphery at Moundville were constructed using kin-based labor whereas the mounds on the central axis of the site were constructed using work crews with laborers drawn from the overall population. This division indicates that while a power perspective was present during the construction of the site there was still a strong kin-based, heterarchical mentality in the organization of labor and material resources. Having both of these elements present at a single time in history, most mounds being constructed in a 100-year time span, supports the idea that there might have been some heterarchical competition between the central authority and the kin-based segments. In discussions of complex societies, one important assumption is that when power in a central authority increases, the bonds of kinship weaken (see Gailey 1985; Iannone 2002). Individuals or groups of increased authority redirect the control of economic and material resources away from kin groups towards a governing entity by emphasizing an ideology that is based on social status. Kin-based organizations are always present in society, but control of their members would likely diminish as a centralized political structure intensifies. This pattern of decline in kin-based leadership does not appear to be present at Moundville. The elite attempted to control labor and produce large earthen monuments as testaments to their power, yet appear to have still allowed competitive mound building to occur, which based on labor estimates would suggest they were constructed by small to average-size kin groups. Mound building by segmentary kin groups would have detracted from elite constructions indicating that, while a power perspective was at play, there was still a strong emphasis on kin-based segments.

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9 Dual labor organization models for the construction of monumental architecture in a corporate society

Anthony James DeLuca

Introduction

Architectural energetics can be used to infer directly political, social, and economic power relations, and is most often applied to state systems (Abrams and McCurdy, Chapter 1). This chapter argues that architectural energetics can also be used to infer labor organization in archaeologically defined cultures that have a less complex scale of political hierarchy. This is done through an analysis of construction methods, logistical constraints, supportive archaeological data from other contexts, and cross-cultural comparisons with other architectural energetics studies.

The case study for this chapter is focused on the Teuchitlán culture of Jalisco, Mexico. The Teuchitlán culture is one of many cultures in West Mexico during the Late Formative to Classic periods (300 BCE–450/500 CE) that share in the tradition of burying some of their dead in shaft and chamber tombs. The Teuchitlán culture is noteworthy among its contemporaries for the large number of circular ceremonial buildings concentrated around the Tequila volcano and surrounding valleys, although such buildings are found elsewhere in West Mexico. The site of Los Guachimontones has the largest number of ceremonial buildings in the Tequila valleys with Circle 2 being one of the largest in the region. The unique form of these buildings, coupled with data from excavations of Circle 2, allow for a nuanced breakdown of labor expenditure used to construct one such temple in this region.

Theory

In architectural energetics studies, scholars typically deal with large stratified societies that have centralized rulers such as kings or lords. These centralized rulers have the authority and power to make use of corvée labor by issuing a labor tax (Moseley 1975) or by throwing an obligatory work feast (Kolb 1994, 1997). Rulers used their recruited labor to construct large monumental buildings such as pyramids (Murakami 2010), palaces (Abrams 1989, 1994; Ogburn 2004), and infrastructure (Protzen 1983). Their expressions of power are evident on the landscape to all that see

these works, whether ancient or contemporary (Trigger 1990). However, corvée labor is not the only model of labor organization that enables the construction of monumental buildings. Comparatively little scholarship in architectural energetics has focused upon the labor collective (Carballo 2012) and its ability to construct equally impressive architectural features (Bernardini 2003).

The labor collective includes community driven forms of labor organization with an aim towards projects that improve the community as a whole. These community driven projects benefit all the participants directly rather than the organizer alone. Activities for the labor collective include craft production at temples or palaces, creating irrigation canals, road repair, maintaining churches, or clearing brush (Carballo 2012, 247–248). Carballo's model for a labor collective is based on the *tequitl* (Nahuatl "task," "work," "tribute") and *coatequitl* (Nahuatl "snake/twin work") as documented in ethnohistoric accounts in central Mexico, though the practice is also known among the Maya, Mixtec, Zapotec, and Balsas River communities (Carballo 2012, 246–247). The well-known practice of *tequio*, found throughout Mexico, is based on the *tequitl* (Good Eshelman 2011). Smaller tasks were designated as *tequitl* while the larger tasks were designated *coatequitl*.

In Late Postclassic Aztec society, the labor collective was organized by the *calpolli* (Nahuatl "big house"), a corporate based political body centered on small towns, barrios, or neighborhoods (Carballo 2012, 247). The *calpolli* imparted such a strong sense of duty to participate in the labor collective that members were virtually obligated to participate. Failure to meet obligations for the labor collective could result in low-level retribution or even ostracism by the community. The labor collective was self-monitoring with community members watching each other to ensure participation (Carballo 2012, 245, 249–250). The labor collective relied upon repeat interactions between community members. These repeat interactions created bonds of trust and reciprocity that Carballo (2012, 253) states form "thick relationships" (Hardin 2003) that allow for such strategies to succeed. Labor collectives thus did not necessarily need strong centralized rulers, like a lord or king, in order to recruit labor for large projects. Work could be organized by members within the community using a gradually cultivated sense of duty to recruit labor. Despite the community focused level of organization and support, the labor collective could be seized by elites to fulfill an obligatory labor tax levied on the people, blurring the line between corvée and community driven forms of labor organization (Carballo 2012, 248).

Bernardini (2003) hypothesized a similar method of labor organization in his analysis of Hopewell earthworks in Ohio. Scattered across Ohio are a number of earthworks consisting of a circle, square, octagon, and even "roads" (Bernardini 2003, 334). While there is variation in how the earthworks are arranged with respect to one another, there is consistency in the shapes being used across many of these Hopewellian earthwork sites. The earthwork groups are large and cover an area of 30 acres or more, but

are located in a low population density region of small dispersed hamlets (Bernardini 2003, 332). The earthwork groups themselves are separated from their nearest earthwork neighbor by a minimum of 6 km and a maximum of 22 km in the Chillicothe area of the Scioto Valley (Bernardini 2003, 346). Bernardini (2003, 346–348) argues that even with a high population density estimate of one person/km^2 and a conservative period of two and a half months per year over ten years for construction, each earthwork group would have required people to travel from as far away as 22 km to aid in construction. Sites close to rivers could potentially tap into labor as far away as 45 km if people traveled by canoe. Artifact deposition from Hopewell burials and artifact caches indicate that it was not uncommon for the Hopewell to travel great distances for special events (Bernardini 2003, 350).

Based upon the number of earthworks and the frequency in which they were constructed, Bernardini (2003, 350) argues that the construction of these earthworks was a recurring and frequent activity for the Hopewell that necessitated people to travel frequently. The similarity of earthwork forms between groups appears to stem from a shared cosmology among the Hopewell. The repetition in earthwork shapes and the need to travel great distances suggests that the Hopewell people constructed these earthworks in order to be a part of and share in the experience of construction rather than to directly benefit from whatever functions the earthwork may have held (Bernardini 2003, 350–351). The Hopewell organization demonstrates that large-scale construction can be accomplished by cultures which lack centralized and powerful rulers. This paper focuses on a corporate society from Jalisco, Mexico which constructed monumental ceremonial architecture.

Background

The Teuchitlán culture is centered in the north-central area of the state of Jalisco around Tequila volcano and its nearby valleys (see Figure 9.1). The Tequila valleys have an elevation between 1200 and 1400 m above sea level. They are characterized by broad open plains, seasonal arroyos, and steep-sided mountains formed by the Neo-Volcanic Axis crossing the Sierra Madre Occidental. The region is rich in mineral wealth such as obsidian, silver, and opals. The climate is characterized as semi-arid with dry, warm winters and hot, wet summers. Rains occur from late May to September and average about 1,000 millimeters a year.

The Teuchitlán culture dates to the Late Formative to Early Classic periods (300 BCE–450/500 CE) (Beekman and Weigand 2008). The Teuchitlán culture is one of several cultures during this period in West Mexico that share in the practice of burying some of their dead in shaft and chamber tombs. West Mexico is sometimes viewed as a monolithic cultural region due to the shared use of shaft and chamber tombs. Continued work over the last 60 years or so has demonstrated that a patchwork of individual, but

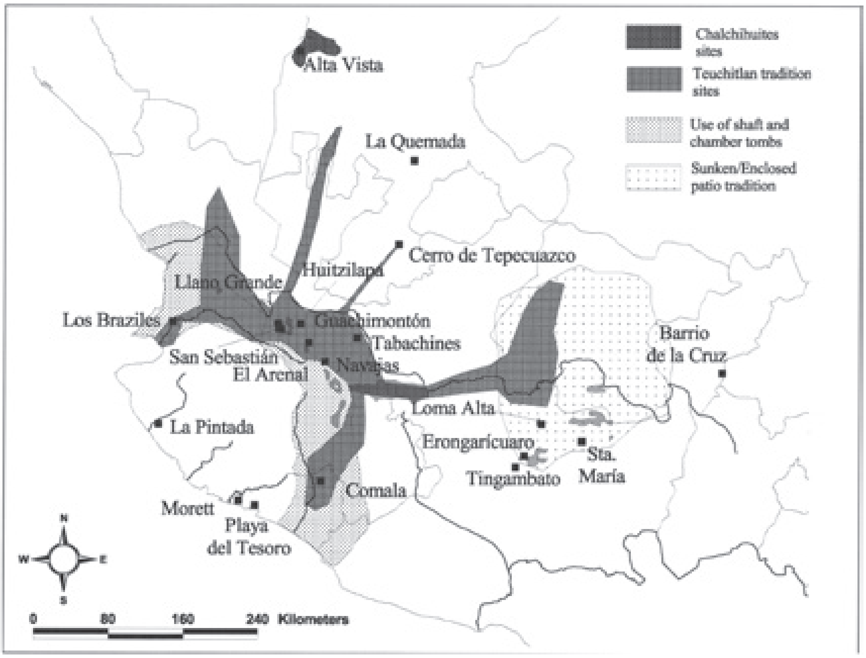

Figure 9.1 Late Formative to Classic period sites in Western Mexico (Beekman 2010, Figure 4). Map by permission of Christopher Beekman

related, cultures was spread across the region. While many of these cultures may have used shaft and chamber tombs for interring the dead, such as the cemetery at Tabachines in the Atemajac valley (Beekman and Galván 2006) or the tomb at Huitzilapa in the Tequila valleys (López Mestas and Ramos de la Vega 2006), this burial practice was neither exclusively used among these cultures nor is it the defining trait of these cultures (Beekman and Pickering 2016). Recognition of local burial practices, ceramic vessel styles, ceramic figure styles, and surface and subsurface architecture has illustrated a divided landscape made up of multiple cultures. While this chapter focuses on the circular architecture constructed by the Teuchitlán culture, much of what we know about this region comes from work on burials and their associated offerings.

During the Late Formative period, the region experienced a surge in construction of surface architecture. Circular temple groups called *guachimontones* were constructed throughout the Tequila Valleys. Guachimontones are heavily concentrated in the southern Tequila valley, but are also found in the Magdalena Lake Basin to the west (Beekman and Heredia Espinoza, in prep.), the northern Tequila valley (Heredia Espinoza 2008, 2017), and southeast of Tala (Beekman 2007). Guachimontones have been reported

outside of the Tequila valleys as far as the Bolaños canyon to the north (Cabrero 1989, 1991), Colima to the south (Olay Barrientos and Morton 2015), and Guanajuato to the east (Cárdenas Garcia 1999). Guachimontón locations can vary from the valley floor to mountain ridges, but are often found to be located on piedmonts overlooking a wide valley area.

Guachimontones typically consist of a flattened patio space. In the center of the space a circular, stepped altar is constructed. Along the circumference of the patio is a ring shaped platform called a banquette. Constructed on top of the banquette is an even number of quadrangular platforms that number as few as four to as many as sixteen. These platforms can have secondary platforms constructed on the lateral sides of the platform (see Figure 9.2). This entire arrangement with these architectural features constitutes a single guachimontón. Guachimontones can be found as singular structures or connected together via a shared platform. Other surface architecture in the region includes ballcourts and household platforms. Ballcourts can be freestanding or can be built off a guachimontón by using a platform as an end platform.

Interpretations of the form and meaning of the guachimontones vary. There are a number of ceramic models that depict simplified versions of guachimontones. The figures that populate such models are often in the midst of a variety of activities such as playing music, carrying other people, tending children, preparing food, or wrapped in blankets that may be related to marriage ceremonies (Gallagher 1983, 108–109). A simpler

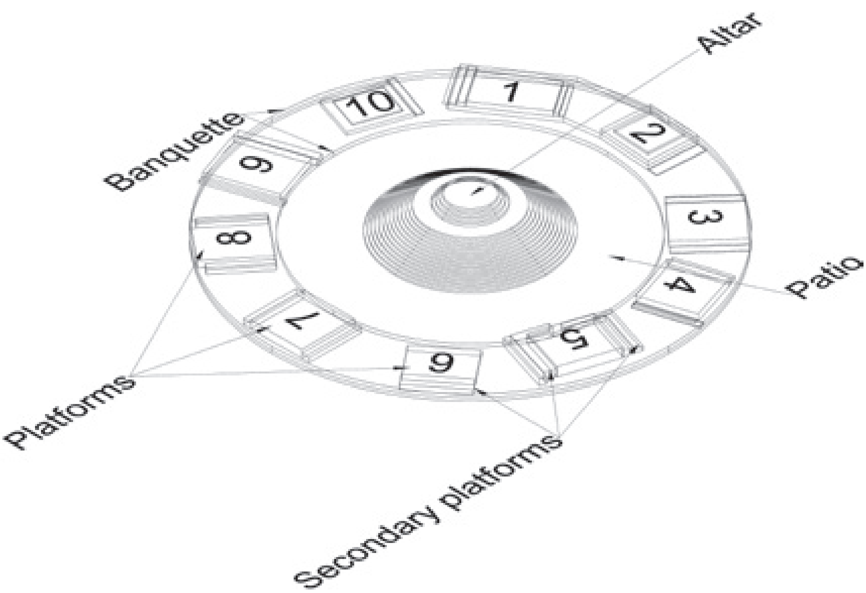

Figure 9.2 Architectural features of Circle 2 at Los Guachimontones (DeLuca 2017, Figure 4.2)

model depicting a single house and a stepped altar shows two groups of armed people engaged in conflict. One group is positioned on the steps of the altar while the other is below (von Winning and Hammer 1972, 62). These models depict guachimontones as more than just ceremonial centers. Guachimontones appear to be community centers in which people gathered together for a wide range of activities including conflict.

Three political models have been hypothesized for the Teuchitlán culture within the Tequila valleys of central Jalisco: a segmentary state (Weigand and Beekman 1998), a collection of chiefdoms (Lopez Mestas 2011), and a corporate system of collective governance (Beekman 2008). Weigand and Beekman's segmentary state model was based on a settlement hierarchy within the Tequila valleys using surface volumes of buildings (Weigand 1990, 39), as well as a core-periphery relationship based on the presence of guachimontones outside of the valleys (Weigand and Beekman 1998, 44). Weigand suggested that elites made use of corvée labor (Weigand 2007, 105) recruited using religious, ceremonial, and ritual authority held by elites (Weigand 1998, 40–42). However, there is little in the way of archaeological evidence to support this model of labor organization. Weigand's (1996) discussion of the construction of guachimontones extended only as far as hypothesizing how the buildings may have been laid out, a hypothesis later questioned and partially refuted (DeLuca 2017; Hollon 2015).

Lopez Mestas' political model for a collection of chiefdoms relies more on archaeological evidence. Lopez Mestas suggests that sites within the Tequila valleys were ruled independently by lineage or clan-based chiefs who temporarily banded together to defend the valleys (Lopez Mestas 2011, 475–476, 479). While Lopez Mestas provides a convincing argument for her political model, she does not make specific proposals as to how labor was organized. She suggests that elites would have held events in which they would try to convince people to donate to them in the form of crafts or domestic surpluses. With these newly accumulated goods, elites would hold larger events and try to gain control over even more goods (Lopez Mestas 2011, 251). Lopez Mestas' model, in which elites attempted to gain status and economic capital, is similar to how Dietler and Herbich (2001) describe their voluntary work feast model. In this model, hosts feed guests in exchange for labor contributions. It would take little effort for elites to request labor instead of goods during these events.

Based on excavations at Llano Grande and Navajas, Beekman proposed an alternative model focused on local dynamics. Beekman (2008, 415, 430) proposes a model in which the Teuchitlán culture centers were ruled by corporate groups composed of lineages, families, or clans that cooperated in a broader form of collective governance. Beekman's analysis of one guachimontón at Llano Grande and two guachimontones at Navajas, along with data from mortuary contexts, supports a model of competing and cooperating lineages.

Three guachimontones examined by Beekman contained a number of interesting variations of construction and design within their respective platforms. Llano Grande's platforms ranged from a simple stone outline with earthen fill to stacked stones and earth. At Navajas, Beekman found similar irregularities in the construction of Circles 1 and 5. At Circle 5, the smaller of the two, one platform was constructed with a single row of stones, two platforms used boulders in their fill, and three platforms were constructed using uniformed stones (Beekman 2008, 424). The altar of Circle 5 was also irregularly constructed. The southern half of the altar was constructed with very tight-fitting stones with little earth or clay fill. The northern half of the altar was constructed using mostly clay with some stones added (Beekman 2008, 425). Circle 1, the larger guachimontón, has four taller and four shorter platforms in an alternating arrangement on the banquette. Beekman hypothesized that the four taller platforms were expanded as the four shorter platforms were added to the guachimontón. Two of these platforms were excavated to determine whether the taller platforms were indeed expanded later. Instead, Beekman discovered that the taller platforms were constructed to their respective height in one event and showed no indication of expansion. Further, both platforms were constructed in a similar manner using a layer of clay followed by layers of sand. The alternating pattern of tall platform to short platform was thus planned (Beekman 2008, 426). Beekman argues that the differences in construction between platforms indicate that separate labor groups were employed for platform construction.

The cemetery at Tabachines and the tomb at Huitzilapa support the lineage model within the Teuchitlán culture. Several tombs at Tabachines include multiple interments that appear to be sequential because remains were pushed to the side (Beekman and Galván 2006, 264). Five of the six individuals recovered from Huitzilapa were found to share a genetic defect in the spine suggesting these five people were closely related (Pickering and Cabrero 1998, 74–75). Combined with the great wealth of goods in the tomb, this lends credence to the idea that lineages played an important role within the Teuchitlán culture (Beekman 2008, 218). Differences between platforms and familial association within tombs may indicate competition and status signaling between these lineages (Beekman 2008, 423). However, these differences may also be attributed to different levels of skill, construction practices, or resources by participating lineages. No one platform appears to dominate over the others in terms of size. This may suggest that individual lineages may have been unable to dominate the other lineages and solidify their place as a royal lineage (Beekman 2008, 429).

In order to construct the guachimontones, elites would have had to command a substantial amount of labor. Elites, however, did not have buildings that could be clearly interpreted as palaces or other elite structures (Beekman 2008, 417). It would appear that elites might not have had enough power in order to recruit a sufficient amount of labor to construct large personal projects such as a palace. To complete large projects, elites would have had

to cooperate and pool their resources. Elites may have relied on labor from within their family, lineage, or clan, but could have recruited labor from within their social network. The amount of labor required to construct a guachimontón, which is not evident in other constructions in the region, may have been justified by the need to create a space in which to perform any necessary rituals and religious activities for the community (Beekman 2008, 230).

Los Guachimontones

The site of Los Guachimontones is located in the foothills of the Tequila volcano about one kilometer north of the town of Teuchitlán (see Figure 9.3). Los Guachimontones consists of two sectors. The lower sector and the entire site are referred to as Los Guachimontones while the upper sector is referred to as Loma Alta. The entire site contains 14 guachimontones, 4 ballcourts, and numerous residential structures and terraces along the hillsides. Recent survey work by Verenice Heredia Espinoza has estimated the site of Los Guachimontones to be 369 hectares during the Late Formative to Classic periods during which the guachimontones and ballcourts were constructed (Heredia Espinoza and Sumano Ortega 2017, 29). Based on this area, the population is estimated to be 3,690 to 9,225 people with a mean population

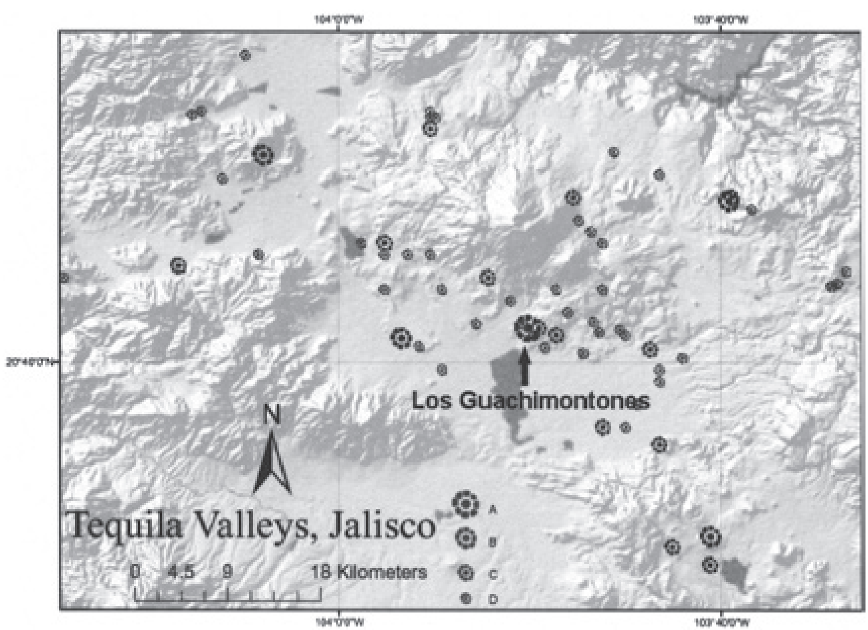

Figure 9.3 Teuchitlán culture sites in the Tequila Valleys (modified from Beekman 2016a, Figure 5). Map by permission of Christopher Beekman

Table 9.1 Chronological phases in the Tequila Valleys

Phase	*Period*	*Dates*
Tequila IV	Classic	200 – 450/500 AD
Tequila III	Late/Terminal Formative	100 BC – 200 AD
Tequila II	Late Formative	300 – 100 BC
Tequila I	Middle Formative	1000 – 300 BC

of 6,458 (Heredia Espinoza and Sumano Ortega 2017; Heredia Espinoza personal communication 2017).

Occupation at Los Guachimontones begins during the Tequila I phase (see Table 9.1). At this time, activity at the site appears to be restricted to the household level with no associated monumental construction. Construction of public architecture began in Tequila II, and Circle 2 was constructed in Tequila III (Beekman 2016b). During the Tequila IV phase, there is a decline in monumental construction. At the end of the Tequila IV phase and beginning of the El Grillo phase (450/500–900 CE), there is a decline in occupation of the site.

The Proyecto Arqueologico Teuchitlan (PAT) under the direction of Phil Weigand began excavations at Los Guachimontones in 1999. By 2008, PAT had excavated six guachimontones, tested three guachimontones, two ballcourts, and a residential area in the lower ceremonial center and part of Loma Alta (Weigand et al. 1999; Weigand and Garcia de Weigand 2000a, 2000b, 2002; Weigand and Esparza Lopez 2008). This chapter focuses on Circle 2, the second largest guachimontón at the site (see Figure 9.4). Circle 2's overall diameter is 99 m. The lower patio construction layer and the outer diameter of the banquette extend to the full diameter. The banquette varies in width from 13.07 m at its narrowest to 17.01 m at its widest and averages 15.34 m in width. The upper patio construction layer and inner diameter of the banquette is thus estimated to measure 68.32 m. The overall width of the altar is 37.5 m in diameter with a height of eight meters. The top surface diameter of the lower tier of the altar is estimated to be 20.84 m in diameter with a height of 5.71 m. Measurements of the upper tier of the altar and its construction are unknown and thus not factored into this energetics analysis. Circle 1, while larger and constructed earlier than Circle 2, had suffered damage from farming and erosion and was not fully excavated. Therefore, Circle 2 is the largest surviving public construction at the site and the best opportunity to establish an upper limit to the amount of labor that could be mobilized at Los Guachimontones.

Circle 2 is constructed from four different materials. The fill of the architectural features is composed of combinations of earth, clay, *toba*, and aggregate in the form of unshaped cobbles. Toba is a local term for a material described as "specks, pebbles, or small cobbles consisting of semi-consolidated or consolidated *jal* [volcanic material] in which the cement agent is yellow and/or

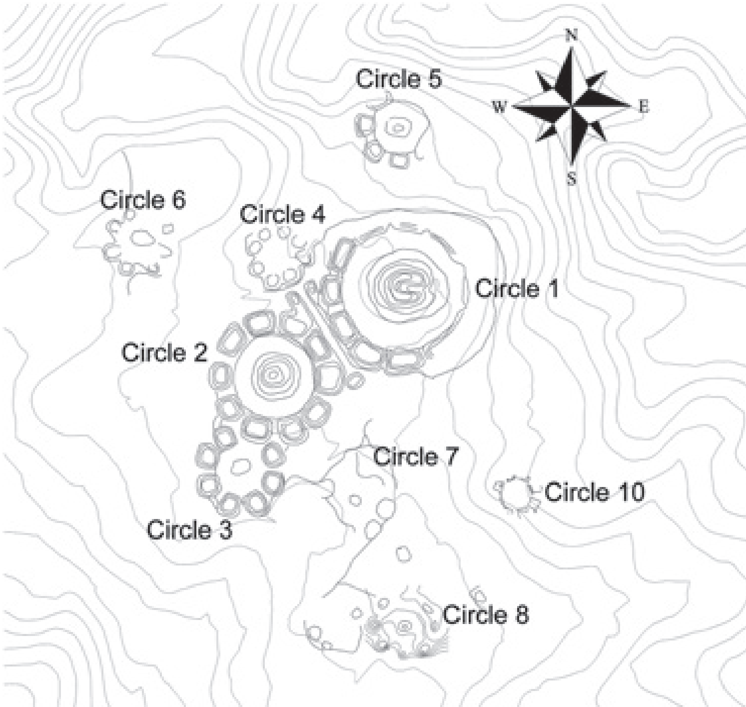

Figure 9.4 Map of the ceremonial center of Los Guachimontones (DeLuca 2017, Figure 4.1). Image courtesy of PAT

grey/yellow ochre" (Weigand et al. 1999, 19). The facing for Circle 2 is composed of unshaped cobbles set in a clay mortar. Covering the cobble facing is a layer of clay known as *aplanado*, which was fired at some point to create a hard orange outer surface. The patio may have once had a floor made of aplanado, but only small sections have been preserved.

The construction materials used in Circle 2 were not used consistently across its architectural features. Each architectural feature, such as the patio or platforms, was constructed following different methods. The patio was composed of two construction layers. The first layer consisted of clay mixed with a large amount of toba. This was followed by a second layer consisting of clay with little to no toba. The fill of the banquette was composed of one to three layers of clay mixed with varying amounts of toba. Excavations into the platforms and into the banquette demonstrated that the composition of the banquette changed depending on the location within the guachimontón. The altar is composed of five separate construction stages termed Altar-sub 1 through 5 with 5 being the earliest construction and 1 being the latest. Each altar stage consisted of a truncated cone that expanded outward into the patio and upward enlarging the previous construction.

The platforms exhibit the most variation of any architectural feature in Circle 2. All but one platform contained a large portion of clay or earth mixed with aggregate. Only Platform 1, the center of three platforms constructed on top of Ballcourt 1, contained only clay with no layer of aggregate construction material. Some platforms, like Platforms 3, 6, 8, and 10, were constructed using a layer of clay and a layer of aggregate fill in all or part of their construction. Others used aggregate fill in differing ratios like Platforms 2, 7, and 9. Platform 5 is unique in that it has a small mound of clay with a retaining wall on one side surrounded by aggregate mixed with clay.

Not only are the platforms constructed differently, but they also display variations in size. In order to estimate the volume of the construction materials, Circle 2 was divided into different architectural features to ensure an accurate total estimate. Length and width measurements for each architectural feature were obtained from plan drawings or site maps. Depth or height measurements were obtained from profile drawings, AutoCAD maps with Z-coordinate data, or textual descriptions from reports. The volume of earth or clay to aggregate was estimated using a dot matrix placed over excavation drawings. Further details on the calculation of volumes can be found elsewhere (Deluca 2017). Of Circle 2's ten platforms, Platform 5 has the largest volume with 405.42 m^3. Platform 1 is a close second with 394.5 m^3. Half of the other eight platforms have a volume of less than 300 m^3 while the other half have a volume over 325 m^3. Platforms 6, 7, 9, and 10 have volumes over 325 m^3 with Platform 10 having the largest volume of the four with 345.48 m^3. Platforms 2, 3, 4, and 8 have volumes less than 300 m^3 with Platform 4 having the smallest volume at 252.13 m^3. It would be tempting to claim there is a pattern in platform volume that is split along an axis formed by Platforms 1 and 5 (see Fig 9.2); however, platform volume is not necessarily indicative of the labor expended to construct each platform.

Energetics

The rates of work used in my energetics analysis of Circle 2 come from Abrams (1994), Milner et al. (2010), and Murakami (2010) (see Table 9.2). The rates of work used by Abrams (1994) for the procurement of cobbles, the construction of earthen fill, and the transportation of materials are included in this analysis. Milner et al. (2010) provided a rate of work for the procurement of clay and an adapted rate of work based on the presence of gravel within the clay that was used for the procurement of toba. Milner et al. (2010) was chosen over Erasmus' (1965) rate of work due to the heavy use of clay in construction over any loose, sandy soil used in Erasmus' experiments. While Milner et al.'s (2010) rate of work utilizes stone hoes, I have argued elsewhere (DeLuca 2017, 79–80) that it was possible the Teuchitlán culture made use of a digging stick like the one later used by the Aztecs (Donkin 1970). Murakami's replicative experiments

Table 9.2 Rates of work

Procurement	
Clay	1.13 m^3/p-d
Earth	2.6 m^3/p-d
Toba	0.85 m^3/p-d
Cobbles	$m^3/p-d=(V*2560)/7200$
Transport	
	$m^3/p-d=Q\times\frac{1}{(L/V)+(L/V')}\times H$
Clay and *toba*	0.094 m^3/p-d
Earth	1.875 m^3/p-d
Cobbles	0.938 m^3/p-d
Construction	
Fill construction	4.8 m^3/p-d
Walls	0.8 m^3/p-d

Figure 9.5 Modern road from the ceremonial center of Los Guachimontones to the natural spring at the base of the hill. Image courtesy of Google Earth

for the construction of walls at Teotihuacan were based on walls constructed of unshaped rocks and mud. These walls are more similar to the facing and retaining walls at Los Guachimontones than those analyzed by Abrams at Copan.

For this architectural energetics analysis, several assumptions were made. I have argued in more detail elsewhere the justification for these assumptions (DeLuca 2017), but they are summarized below. First, a five-hour workday was used to calculate person-days (p-d). Five-hour work days have become a standard in energetics calculations, though other work day periods have also been used (Hammerstedt 2005; Moyes et al. 2016). Second, the clay used in construction fill was assumed to come from one kilometer south of the ceremonial center near a natural spring (see Figure 9.5). Weigand had

proposed varying distances for the clay used in construction from 800 m, 1 km, or further (Weigand et al. 1999, 20; Weigand and Garcia de Weigand 2000b, 72; Weigand and Esparza Lopez 2008, 161). The earth and cobbles used in construction are assumed to come from around the ceremonial center at a maximum distance of 100 m as both materials are readily available on the surface.

For the toba, Weigand noted that a quarry near the town of La Mora, three km away, produced toba that was similar to what was found at the site (Weigand et al. 1999, 19). However, it is unknown whether the toba found in excavations is, in fact, similar to the toba mined at La Mora. Weigand also describes the clay mixed with toba as "well sorted," which suggests that some sort of processing of the material took place before mixing. Perhaps the toba was mined into chunks, ground, and then mixed with clay. However, it cannot be said at this time if the mixing occurred at the construction site or at the place of procurement. Processing clay, removing large inclusions, and adding any needed temper during ceramic production is a familiar task for the people of the Teuchitlán culture. As Johns (2014, 40–45) notes in detail, sometimes a tremendous amount of work went into processing the clay and temper used to create ceramic vessels in the region.

Due to the uncertainty regarding the source(s) of the toba, and whether or not any processing and mixing actually took place, I made a set of assumptions regarding the material that are discussed in further detail elsewhere (DeLuca 2017). For this energetics analysis, I assume that the toba was procured from a distance of one km. The same rate of work for the procurement of clay is used for clay mixed with small to medium amount of toba. Clay mixed with a large amount of toba uses a rate of work based on the slowest rates of work conducted by Milner et al. (2010) with the idea that procuring the toba dense clay would be a slower task.

Applying the rates of work in Table 9.2 to the estimated volume of materials used to construct Circle 2 results in a total of 112,651 p-d. This includes all secondary platforms that were added to the primary platforms and all five construction stages of the altar. If a comparison to Structure 10L-22 (Abrams 1994) can be made, the palace for a king required less than one-quarter the amount of person-days that Circle 2 required. If four such palaces were constructed in a 150-day period, 659 people, or 13.18% of Copan's labor pool, would be utilized. This places the construction requirements of four palaces in a Maya city-state as less than the amount of labor required for the construction of Circle 2 in both number of laborers and percentage of the labor pool.

The real story, however, is not in the total expenditure of labor, but how labor can be broken down into the component parts of the guachimontón. The most labor intensive architectural features of Circle 2 are the patio, banquette, and the altar as a whole. Each of these features requires more than 20,000 p-d to construct. Nine of the ten platforms, including all secondary platforms, require less than 3,000 p-d to construct.

Table 9.3 summarizes the estimated number of person-days needed to construct each architectural feature of Circle 2. These numbers are somewhat meaningless without further context. Logistical constraints of population size, number of construction events, and length of time dedicated to construction all influence our interpretation of how Circle 2 was constructed. Like Abrams, I tested the feasibility of one construction event despite evidence from excavations indicating multiple construction stages took place. While a period of 60 days was used by Abrams (1987, 490; 1989, 66, 73; 1994, 106), and later used by others in their energetics assessments (Murakami 2010; Ortmann and Kidder 2013; Rosenswig and Masson 2002), this period of time is much too short given the lengthy dry season in central Jalisco. Sixty days is less than one-third of the entire dry season in the Tequila valleys. Instead, I chose three different periods to test the feasibility of a single construction event. Periods of 100, 133, and 150 days were chosen as they mark one-half, two-thirds, and three-quarters of the dry season. Table 9.4 indicates the number of laborers needed to construct Circle 2 in each of these periods. Other workday periods have also been used in architectural energetics analyses that are tailored to their respective regions (Carmean 1991; Kim 2013; McCurdy, Chapter 10).

Table 9.3 Person-days needed to construct each architectural feature

Architectural feature	*Labor-days*
Patio	38,946.93
Banquette	21,182.09
Altar	27,722.23
Platform 1	4,925.5
Platform 2	2,330.8
Platform 3	2,350.44
Platform 4	1,738.33
Platform 5	2,374.13
Platform 6	2,391.40
Platform 7	2,157.45
Platform 8	1,888.66
Platform 9	1,853.64
Platform 10	2,795.06

Table 9.4 Estimated amount of laborers to construct Circle 2 (112,651.41 p-d)

Construction period (days)	*Number of laborers*
100	1126
133	847
150	751

Table 9.5 Percent of labor pool required to construct Circle 2 in one season

Population	*Labor pool*	*Laborers for one season*		
		1126	*847*	*751*
3690	738	152.57%	114.77%	101.76%
6458	1292	87.15%	65.56%	58.13%
9225	1845	61.03%	45.91%	40.70%

If we follow Abrams' (1996, 106) assumption for Copan that 20% of a population are available for labor conscription, we can estimate the number of people available for construction for the minimum, maximum, and mean population of Los Guachimontones. Table 9.5 compares the number of people available in the labor pool to the estimated number of people needed to construct Circle 2 from Table 9.4. This relationship is expressed as a percentage of the labor pool needed for each day period.

Table 9.5 shows that the labor needed to construct Circle 2 requires at least 40% of the labor pool or more. The labor requirements placed on the minimum population estimate exceed the available number of people in the labor pool. For comparison to a corvée labor system, the most labor-intensive structure examined at Copan by Abrams (1994) was Structure 10L-22, a palace for Copan's 13th king, which required an estimated 24,705 p-d to construct. If constructed during a 60-day period, only 412 people, or 6% of the available labor pool of 5,000 people, were needed to construct the palace. This includes all the specialized labor such as sculpting and plaster making that would have normally required more time with fewer people (Abrams 1994, 106, 133).

As with other large structures, Circle 2 was most likely constructed over several seasons rather than just one season (Murakami 2010, 2015; Webster and Kirker 1995). The most obvious stages of construction within Circle 2 are evidenced in the altar. The altar underwent five distinct construction stages with an initial construction and four expansions. The construction events for the remaining architectural features of Circle 2 are less clear. However, logical divisions within Circle 2 can be made. For example, Altar-sub 1 cannot be constructed before Altar-sub 5 and Altar-sub 5 cannot be constructed before the patio (see Figure 9.6). Alternatively, the secondary platforms cannot be constructed before the primary platforms and the primary platforms cannot be constructed before the banquette. If the altar is used as the minimum number of construction events for Circle 2, the remaining architectural features can be divided into five construction event groups that each correspond to one construction stage of the altar. I have argued elsewhere for six groups due to logistical constraints (DeLuca 2017). I propose the following six construction event groups. Group 1 consists of the construction of the patio and Altar-sub 5. Group 2 consists of the banquette and Altar-sub 4. Group 3 consists of Altar-sub 3. Group 4 consists

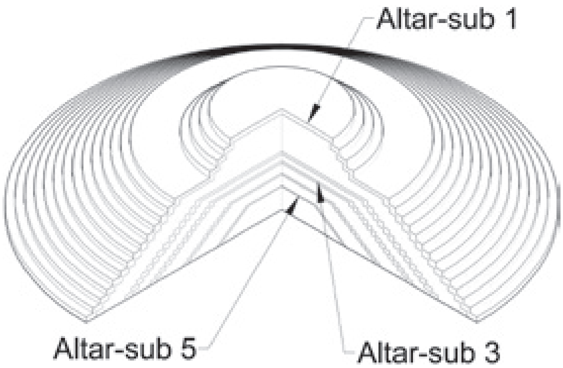

Figure 9.6 Stylized rendition of the altar of Circle 2

Table 9.6 Amount of labor in people needed to construct each event group

	Total person-days	*Construction period*		
		100 days	*133 days*	*150 days*
Group 1	39,916	399	300	266
Group 2	22,930	229	172	153
Group 3	20,000	200	150	133
Group 4	10,129	101	76	68
Group 5	12,938	130	98	87
Group 6	6,625	66	50	44

of all ten primary platforms. Group 5 consists of the secondary platforms and Altar-sub 2. And Group 6 consists of just Altar-sub 1 (see Figure 9.2).

By dividing Circle 2 into these six construction group events, the amount of labor needed per season does not exceed the number of people within the labor pool (Table 9.6). Even if Los Guachimontones had the smallest estimated population and only worked for half the dry season, the most strenuous construction stage would be Group 1 requiring 399 people or 51.08% of the available labor pool. While this percentage is greater than the percentage of the labor pool needed to construct Circle 2 in one season using the largest estimated population and the longest period of time, it is still realistic and attainable for Los Guachimontones.

The labor used to construct Circle 2 can be viewed in a different way. Instead of time being a constraint that dictates the number of laborers needed, the amount of laborers able to be recruited could dictate the amount of time needed to construct Circle 2. Beekman (2008) hypothesized that the Teuchitlán culture was ruled by competing and cooperating ruling families, lineages, or clans. These ruling families would be in charge of performing the necessary rituals and religious activities to ensure that the world would

continue. He proposed each platform corresponds to one of these ruling families and provide these families with a place to perform these needed rituals and activities or to prepare for feasting (after Johns 2014, 108–114).

The patio is the single most costly feature of Circle 2 because of its large volume of clay. Despite its large size and huge cost in labor, the patio is one of the most homogeneously constructed features of Circle 2. Great effort and care was taken to use only two types of construction material without any variability within the layer. This differs greatly from the banquette and the platforms in which we see different construction layers and construction materials within the feature itself. The patio may have been the result of a much larger community effort in which labor from outside the ruling families was temporarily recruited. The larger number of people may have required the cooperation of the ruling families to direct labor efforts to ensure that the patio was constructed before the end of the dry season. This recruitment model seems to fit with Carballo's (2012) labor collective model or Bernardini's (2003) model for the Hopewell earthworks.

Support for the idea of Circle 2 being partially constructed by a community effort comes from the shape of the guachimontón and the ceramic models from the region depicting a simplified version of the structure. The guachimontón itself is a relatively open structure with no high walls or particularly high platforms. While staircases on some platforms and areas of the banquette attempt to direct the flow of movement, one can nonetheless simply climb up onto the structure from any point. The lack of walls, enclosed spaces, or restricted pathways to prevent such actions may be reflective of its inclusive nature. People were free to move around the ceremonial precinct and structures of Los Guachimontones despite its removal from domestic areas (Hollon 2015; Sumano Ortega and Englehardt 2016). As previously discussed, the ceramic models appear to depict places of group activity beyond religious ceremony. Having the community partake in the construction of the patio may create collective social investment and an attachment to the site. While being smaller shareholders than the elites, those in the community that aided in its construction would nonetheless remain part-shareholders of the guachimontón. This investment in the construction of the temple may have fostered social bonds and comradeship in the community (Bernardini 2003).

The banquette would seem to indicate a transition from communal efforts towards competitive action between ruling families. Elites needed to cooperate only so far as to create a banquette in the form of a ring. Within their respective sections of the banquette, elites constructed a space that was best suited to their eventual platform and secondary platform construction. This required planning for the next stage of construction since excavations into Circle 2 show no evidence of expansion to the banquette. Elites that could only manage to construct a narrow section of the banquette were limited the next season by the available space. Likewise, elites that constructed a wider section of banquette were committed to filling that section with a large platform.

The platforms are the final transition to competitive action. Each platform is constructed to a different size using different materials, requiring different amounts of labor investment. The number, position, and construction materials for secondary platforms also differ. Ruling elites were thus unable to recruit the same amount of labor to ensure homogeneity in Circle 2's construction. The ruling elites who agreed to cooperate in construction were thus committed to finishing construction. The change from labor-intensive clay to cost-effective aggregate fill may indicate differences in power between participating lineages. Table 9.7 lists the total number of person-days needed to construct each platform group demonstrating the differences in labor coordinated by associated ruling elites.

If we assume for a moment that the primary and secondary platforms were constructed together and each platform group was constructed by a separate lineage, the number of laborers needed to build each platform group may be the maximum amount of labor each lineage could recruit. If that is the case, the six proposed Event Groups could be tested. As Table 9.8 demonstrates, every Event Group except for Group 1 can be constructed by the labor needed to construct just the platforms.

Table 9.7 Estimated amount of laborers needed to construct each platform group

Architectural feature	*Total person-days*	*Construction period*		
		100 days	*133 days*	*150 days*
Platform 1	4,921	49	37	33
Platform 2	2,326	23	18	16
Platform 3	2,350	20	15	14
Platform 4	1,738	17	13	12
Platform 5	2,374	24	18	16
Platform 6	2,391	24	18	16
Platform 7	2,157	22	16	14
Platform 8	1,889	19	14	13
Platform 9	1,854	18	14	12
Platform 10	2,795	28	21	19
Total		244	184	165

Table 9.8 Estimated number of days needed to construct each group

	Total person-days	*Labor pool*		
		244	*184*	*165*
Group 1	39,916	164	217	242
Group 2	22,930	94	125	139
Group 3	20,000	82	109	121
Group 4	10,129	42	55	61
Group 5	12,938	53	71	79
Group 6	6,625	27	36	40

Conclusions

Forms of labor organization other than corvée labor, such as collective labor, are often overlooked in architectural energetics studies. Circle 2 at Los Guachimontones provides an example of the use of both collective labor and corvée labor in order to construct a monumental building. While Los Guachimontones may not have relied exclusively on collective labor to construct Circle 2, elites made use of existing systems within the Teuchitlán culture to accomplish their goal of creating a ritual and public space for the community. The changes in construction from homogenous layers in the patio to stark differences in construction materials and methods in the platforms highlight this change from communal efforts to lineage competition. Questions arise whether this was standard practice at Los Guachimontones or the entire Tequila valleys or whether this was unique to just Circle 2 or perhaps other large guachimontones. Further work on existing excavation data and perhaps new excavations into guachimontones at other sites are needed in order to better understand labor organization within the Teuchitlán culture. This analysis of Circle 2 highlights the importance of understanding the construction of monumental architecture within cultures outside the traditional bounds of states and strongly centralized leadership.

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10 Peopling monuments

Virtual energetics and labor impact analysis of monumental construction at Xunantunich, Belize

Leah McCurdy

To harken back to the analogy of reverse engineering offered in the Introduction (Abrams and McCurdy, Chapter 1), architectural energetics is also an exercise in reverse bookkeeping. Through the processes of deriving "cost" or investment estimates, we essentially reconstruct ancient construction ledgers. In this way, architectural energetics can be viewed as an avenue to tread in the footsteps of ancient builders and construction managers. Beyond this, architectural energetics is one way to "people" (after Brumfiel 1991; Erickson 2006) ancient construction practices and to conceptualize buildings beyond their stones and mortar (see also Brysbaert 2015). "Peopling" ancient buildings through energetic studies allows us to move beyond elites to all those laborers who contributed to construction efforts and may have only been represented by a tally mark, or less, in an administrator's ledger.

Like monumental architecture, labor is often seen as a monolithic, dehumanized entity. As such, labor is viewed solely as a resource, something to be controlled, rather than work that people actually did. Taking a humanized approach can augment traditional labor control perspectives by "peopling" labor with laborers. This approach also allows for "peopled" understandings of public building and monumental architecture. I prefer the term "public building" to monumental construction because the former implicates public involvement, i.e. people and their effort as a collective community.

To achieve this peopled view, I expand my energetic analyses beyond the estimation of comparative labor investment (total person-days) or total labor population size following the modeling approaches of Elliot Abrams and Thomas Bolland (1999) and Richard Smailes (2011, Chapter 11). Such modeling provides hypothetical reconstructions of laboring groups, their task divisions, and the basis for arguments about supervision and specialization (see also Abrams 1984, 1994). With such analysis to hand, new doors open to consider production systems and coordination, applications of social network analysis, household or personal impact (DeLaine 1997; Erasmus 1965, 283; Murakami 2015), or the ideological implications of community participation in public building (Brysbaert 2015). In general,

I suggest that laborer-focused alternatives to labor control lead to a different perspective on monumental construction and what monumental architecture can represent. In fact, I view built forms as representations of the people involved in their creation, more so than the people who claimed them as representations of their own status or importance.

It is important to recognize that architectural energetics is fundamentally an exercise in modeling (Abrams and McCurdy, Chapter 1). Results are estimates and simulations. In no way do I assert that the person-day totals that I present are representations of literal historical fact or that they actually replicate ancient construction ledgers. They are simulations of realistic possibilities.

El Castillo, Xunantunich case study

I apply this peopled approach to the El Castillo acropolis of Xunantunich, Belize (see also McCurdy 2016) (see Figure 10.1). Xunantunich is an ancient Maya archaeological site that functioned as a mid-level administrative and ceremonial polity center in the Mopan Valley region of the central Maya Lowlands (see Figure 10.2). The Xunantunich hilltop was occupied as early as the Preceramic period (Brown et al. 2011) with significant development through the Preclassic (Brown 2017), decline in the Early Classic (Yaeger et al. 2015), resurgence to its ultimate height in

Figure 10.1 North Façade of the Castillo Acropolis at Xunantunich, Belize

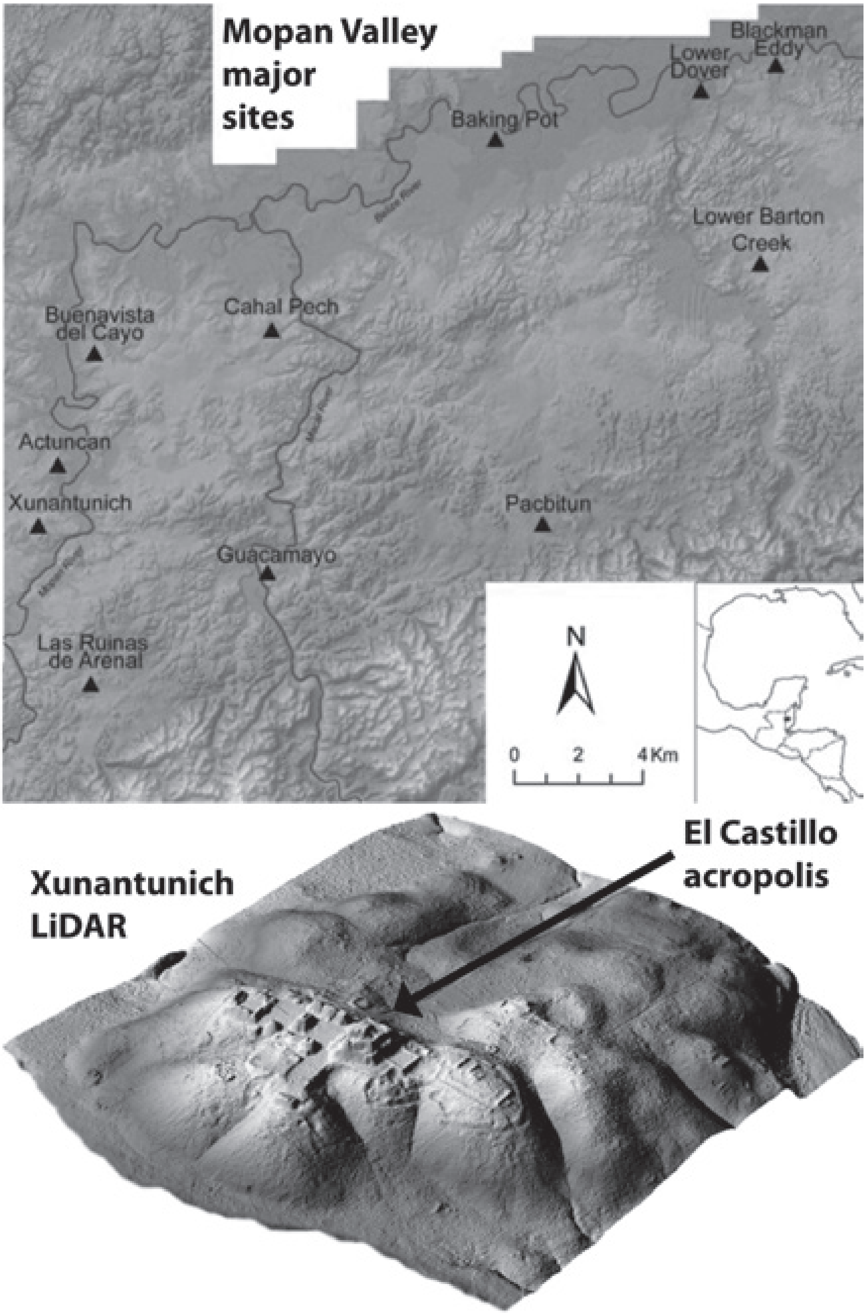

Figure 10.2 Map of the Xunantunich Site Core showing location of the Castillo Acropolis. LiDAR imagery courtesy of Bernadette Cap. LiDAR data copyright Mopan Valley Archaeological Project and Mopan Valley Preclassic Project

the Late Classic period, and sociopolitical disarticulation in the Terminal Classic (LeCount and Yaeger 2010).

El Castillo is the central acropolis at the site. It is one of the largest such features in the region, containing at least eight separate masonry buildings and reaching a total height of 43 m above plaza level. Richard Leventhal (2010) offers a synthesis of El Castillo's construction history based on excavations undertaken during the 1990s and early 2000s. I also conducted excavations and surveys from 2011–2014 to refine this chronology, especially as it relates to previously understudied areas of the acropolis, into nine major periods of construction (see Figure 10.3; McCurdy 2016). To summarize, El Castillo grew from a set of modest low-lying platforms with thatched structures in the Middle or Late Preclassic period (1000–400 BCE or 400 BCE–200 CE; Periods 1a and 1b) to an acropolis of multiple masonry buildings with a footprint of at least 100 × 80 m in the early part of the Late Classic period (Samal phase, 600–670 CE; Periods 2a, 2b, and 2c). By the end of the Late Classic (Hats Chaak phase, 670–780 CE; Periods 3a, 3b, and 4a) and into the Terminal Classic (Tsak phase, 780–890 CE; Period 4b), El Castillo acropolis featured three major levels of occupation, a two-storied central structure, and a monumental stucco frieze.

For this discussion, I concentrate on Period 2b, or the mid-Samal phase, corresponding to approximately 625–650 CE (see Figure 10.3). This period included the construction of three major substructural platforms (Lopez, Uck 1, and Uck 2) that buried all previous features and supported all subsequent features. The original iteration of Structure A-6, known as A-6-3rd, was built atop the northern half of these substructural platforms during Period 2b as well. Structure A-6-3rd comprised three substructural platforms (Moon, Cloud, and Sky) and a superstructure that was removed prior to the initiation of the second iteration (Miller 1996). Leventhal (2010) suggests that Structure A-6-3rd featured vaulted masonry although the substructures could have supported a post-and-lintel thatched building. I reconstruct the A-6-3rd superstructure as a masonry building of 12 rooms (four bays of three rooms each) with its primary axis running east-west and sufficient walking space to the edge of Sky Platform. The southern half of the Lopez Platform surface likely supported post-and-lintel structures, based on evidence from the earlier Macal Platform that was buried by Uck 2 (Hays 1997). Leventhal (2010) interprets this southern complex as the residential area for newly minted Xunantunich rulers at this point in the Late Classic period. The acropolis eventually transformed into a fully ritual complex, with the construction of a separate palace to the north (Yaeger 2010), and back into an elite residence as Xunantunich's political fortunes severely declined in the Terminal Classic (Leventhal 2010; Yaeger 2010).

The size and nature of El Castillo as a composite of buildings dictate a distinct energetic approach, particularly as it relates to labor analysis. A "single-structure approach" (Carrelli 2004, 116) is appropriate for the comparative perspective pursued by Abrams and others. Abrams (1994, 55)

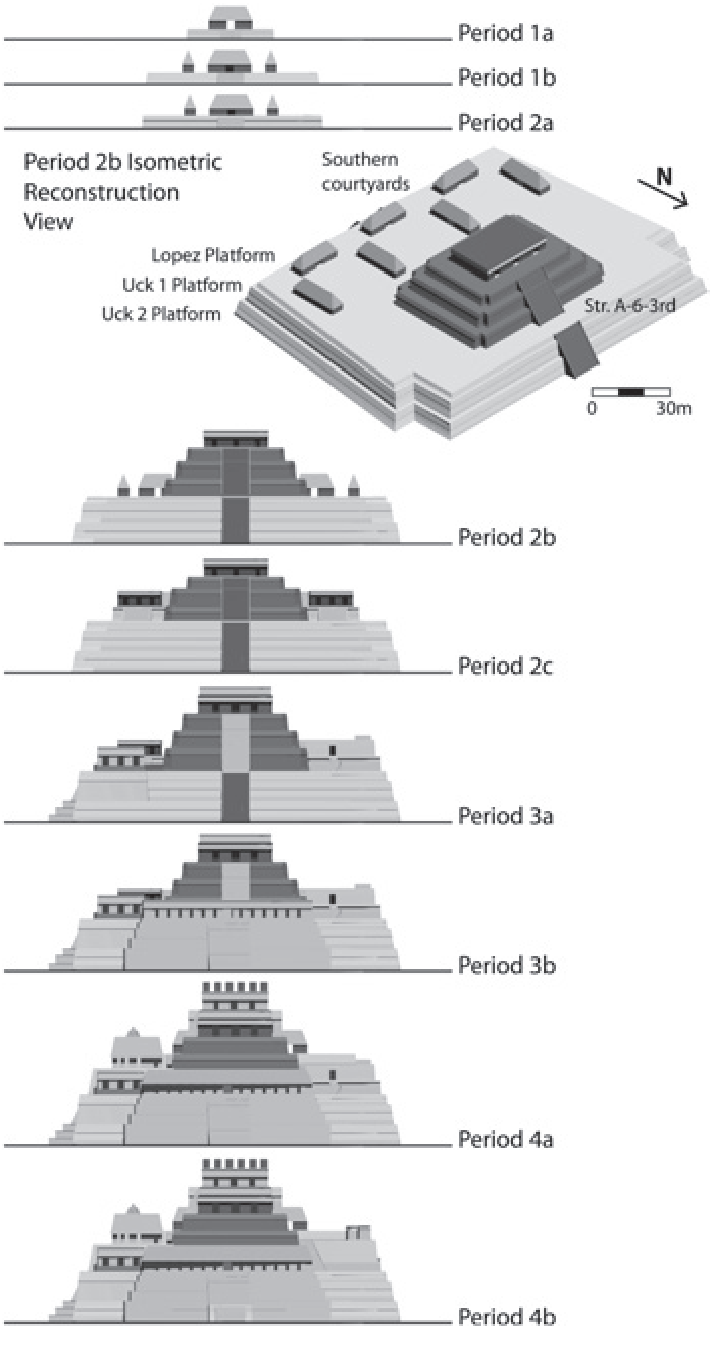

Figure 10.3 Virtual reconstructions of El Castillo Periods 1a–4b with emphasis on Period 2b

notes that one of his motivations to focus on Structure 10L-22 at Copán was its extensive excavation record and the fact that primary interpretations considered it a single-phase structure (see Ahlfeldt 2004 for new interpretations). Large, composite architectural complexes present distinct challenges (see Sherwood and Kidder 2011, 83). Charles Erasmus (1965) and Charles Cheek (1986) studied large-scale complexes and/or multi-building groups but employed basic volumetric methods reliant on few differentiated measures.

Christine Carrelli (2004) and Tatsuya Murakami (2015) present examples of applying energetic analysis to large-scale and composite features although these authors do not focus on labor organization as a theme of investigation. Carrelli (2004) performed detailed analyses, following Abrams' (1994) methods, on multiple structures of the Copán Acropolis to investigate the construction investments of Early Classic rulers. Murakami (2015) addressed five of the largest and multi-phase structures of Teotihuacan to consider the impact of fast-paced nucleation and to reconsider the chronologies previously submitted for these buildings. In this study, I focus on El Castillo, a composite and diachronic feature on the high end of the Maya monumentality spectrum, and apply virtual techniques to expand architectural energetics.

Virtual energetics

Virtual energetics incorporates virtual architectural reconstruction (VARch) to visualize diachronic change, fill current gaps in the understanding of that change with supported hypotheses, and conduct energetic analysis with the benefit of a virtual and queriable dataset. VARch is a relatively new methodology developed by archaeologists from various other applications such as architectural visualization and drafting (McCurdy 2010). The process involves creating 3D representations of architectural features based on digital survey data as well as manual measurements (McCurdy 2013, 2016). To create 3D features that approximate real features as closely as possible and that contribute to a resource useful to further scientific analysis (Eiteljorg 2000; McCurdy 2010; Miller and Richards 1995), I rely on all available information including previous and my own excavation and survey data as well as published interpretations of architectural form and change. In general, VARch also offers a means to visualize the interpretive record to benefit interested parties beyond academia.

In a similar way to Tatiana Proskouriakoff (1963), the famous Mayanist who suggested reconstructions of various complexes (in 2D formats), I too must make reconstructive decisions where evidence is lacking or with very little or no supportive archaeological information. Abrams (1994, 55) did not seek to reconstruct unknown or buried features because he did not wish to extend interpretations beyond the inferential limits of available excavation data and so focused his analysis on well-known buildings or those in

good preservation. Carrelli (2004) chose to focus on detailed excavation records of constructions across the main acropolis at Copán, especially those achieved through deep and extensive tunneling investigations. Both positions are valid and understandable, especially as the application of architectural energetics implicates several layers of hypothetical projection. I consider VARch as an opportunity to spawn and test new hypotheses, determine the most plausible, and embed them within a cohesive visualization. I use a paradata documentation scheme to provide evidentiary transparency for all VARch models I create (McCurdy 2010, 2016).

I virtually reconstructed all features of El Castillo architectural history using 3DS Max software (McCurdy 2016, 389–399). I structure each virtual reconstruction of each period as a series of building features, organized as layers. For example, Period 2b includes ten stand-alone or composite features (including substructures and multiple components of superstructures). 3DS Max allows for the digitization and near automation of volumetric calculations for architectural energetics. Using simple command functions embedded within the software, raw volumetric and dimensional measurements can be extracted from the virtual model as needed. Estimates of the cubic meter volume of a substructural platform, for example, derived from 3DS Max harness sophisticated algorithms to compute figures with more precision and accounting for more detail (such as angled corners) than can be easily achieved through hand calculations. Further, as a consequence of software design, these volumetric figures are embedded within the 3D files. Thus, they are stored in a venue beyond those created for energetic analyses. This enhances data storage reliability and ensures that any future investigators interested in these 3D reconstructions have direct connections to volumetric datasets.

I use these raw volumetric figures drawn from 3DS Max to derive a series of calculated volumetrics that must be extrapolated from the available measurables. Next, to be applicable for use in person-day calculations, some volumetrics need to be converted to different units, combined, or disarticulated to apply to specific work rates. Once volumetrics are in their refined states, I conduct the time-labor calculations using work rates I deem appropriate for El Castillo contexts (Table 10.1; see McCurdy 2016, 402–427). Generally, I follow the time-labor estimation procedures laid out in the Introduction (Abrams and McCurdy, Chapter 1).

The calculation of "wholesale" time-labor "cost" of construction for each El Castillo phase is straightforward. Combine all person-day estimates for all features of all structures to derive a summary person-day total for each phase. Figure 10.4 compares these wholesale person-day results. Mid-Samal phase Period 2b obviously dwarfs the other periods in terms of energetic cost. These results are also interesting because Periods 3a and 4a are typically considered to be the most "expensive" in the chronology of El Castillo and its sociopolitical context (Leventhal 2010). However, as the reconstructions demonstrate, the features of Periods 3a and 4a were built

Table 10.1 El Castillo Period 2b wholesale person-day and labor estimates including volumetric data, work rates, person-day estimates, and schedule

Operations & tasks	*Volumetrics (3dsMAX)*	*Units*	*Work rates*	*Calculated p-d*	*Scheduled 100-day by task*	*Persons*	*Days*
Removal							
Previous building	245.12	m^3	2.6 m^3/p-d	94.28	removing previous building	9	10
Procurement							
Limestone	16,643,737.15	kg	1,200kg/p-d	13,869.78	quarrying limestone	173	80
Earth	21,143.31	m^3	2.6 m^3/p-d	8,132.04	digging earth	407	20
Cobbles	107,301,490.32	kg	7,200 kg/p-d	14,902.98	collecting cobbles	745	20
Sascab (marl)	6,491.87	m^3	1m3/0.5 p-d	3,245.93	excavating sascab	162	20
Wood for lintels	7.02	#	1.4 lintel (7 lengths)/3.76 p-d	18.84	felling trees for lintels	2	20
Transport							
Limestone	6,374.47	m^3	m^3/p-d = Q × 1/(L/V + L/V') x H	5,099.57	transporting limestone	64	80
Earth	21,143.31	m^3		11,276.43	transporting earth	564	20
Cobbles	57,596.08	m^3		107,512.68	transporting cobbles	1,344	80
Wood for lintels	7.42	m^3		3.96	transporting wood for lintels	2	20
Sascab (marl)	6,491.87	m^3		2,596.75	transporting sascab	43	60
Water	205.73	m^3		34.29	transporting water	2	80
Lime	303.57	m^3		121.43	transporting lime	2	75
Manufacture							
Finish masonry	1,338.45	m^3	1m^3/11.6 p-d	15,526.00	cutting finish blocks	183	85
Core masonry	1,338.45	m^3	1m^3/1.16 p-d	1,552.60	cutting core masonry blocks	19	80
Lintels	21.05	m^2	1m^2/1 p-d	21.05	cutting lintels	2	20
Lime burning	303.57	m^3	0.03 m^3/p-d	10,118.98	burning lime	135	75
Render mixing	991.22	m^3	0.22m^3/p-d	4,505.55	mixing renders	56	80

Construction							
Core masonry surface	1,338.45	m^3	$3.5m^3$/p-d	382.41	constructing core masonry	4	85
Finish masonry surface	1,338.45	m^3	$1.06m^3$/p-d	1,262.69	constructing finish masonry	15	85
Constr. cells (cobbles)	15,309.46	m^3	$3.5m^3$/p-d	4,374.13	constructing pin walls	55	80
Constr. cell floors	6,063.56	m^3	4 m^3/p-d	1,515.89	laying construction floors	19	80
Interior fill	535.38	m^3	$4.8m^3$/p-d	111.54	laying fine fill wall backing	2	50
Cobble subflooring	9,768.65	m^2	9.6 m^2/p-d	1,017.57	laying cobble subfloor	68	15
[1]Decorative stucco	22.01	m^3	$1m^3$/14.3p-d	3,14.71	stuccoing relief design	31	10
Plastering	15,211.85	m^2	$10.42m^2$/p-d	1,459.87	applying plaster	97	15
Painting (ext solid color)	15,211.85	m^2	$45.10m^2$/p-d	337.29	painting exterior solid color	34	10
Painting (stucco color)	88.03	m^2	$1.06m^2$/p-d	83.05	painting stucco color	9	9
Thatched spstr.	423.94	m^2	p-d = -13.838 + 1.832 (m^2)	762.81	building thatched structures	38	20
			Total Calculated p-d	**210,255**	**Scheduled 100-day est (At most):**	**3,942**	
			100-day standard est	**2,103**			

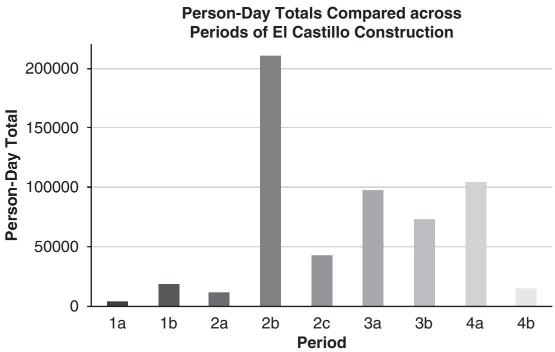

Figure 10.4 Comparison of wholesale person-day estimates for all El Castillo construction periods

atop the foundations of previous structures, initiated in the architectural explosion of Period 2b. Thus, these later periods do not reflect comparatively costly efforts.

The traditional endpoint of energetic analysis involves extrapolating labor force totals from such wholesale person-day estimates. Within the Maya world, this is typically accomplished by dividing the total number of person-days by 100 to reflect a 100-day building season (after Abrams 1994; Abrams and Bolland 1999). If applied to the wholesale person-day estimate for Period 2b (see Figure 10.4), we could project a total laboring group of approximately 2,100 laborers. Ending there provides an inaccurate estimation of labor group size and tells us little about those laborers. As I emphasized at the outset, my interest lies in diving into these person-days to humanize construction labor. I extend energetic analysis in three ways to produce more detailed and realistic labor projections through: 1) scheduling models; 2) segmented feature analysis; 3) project duration and timing alternatives.

Scheduling models

Wholesale labor group estimates using a 100-day standard, for example, assume that all laborers were working across all 100 days. To project scheduled models, I follow and amend parameters suggested by Abrams and Bolland (1999) to separate and sequence tasks that a particular construction event entailed. Table 10.1 compiles the energetics analysis for all efforts of Period 2b construction, including a schedule of days for each task. This is then used to project a scheduled model of Period 2b labor group size. Figure 10.5 visualizes that schedule and simulates the organization of labor across the entire project duration following Smailes' (2011) visualization style. I use the 20-day *winal* unit known from Yucatec Maya contexts

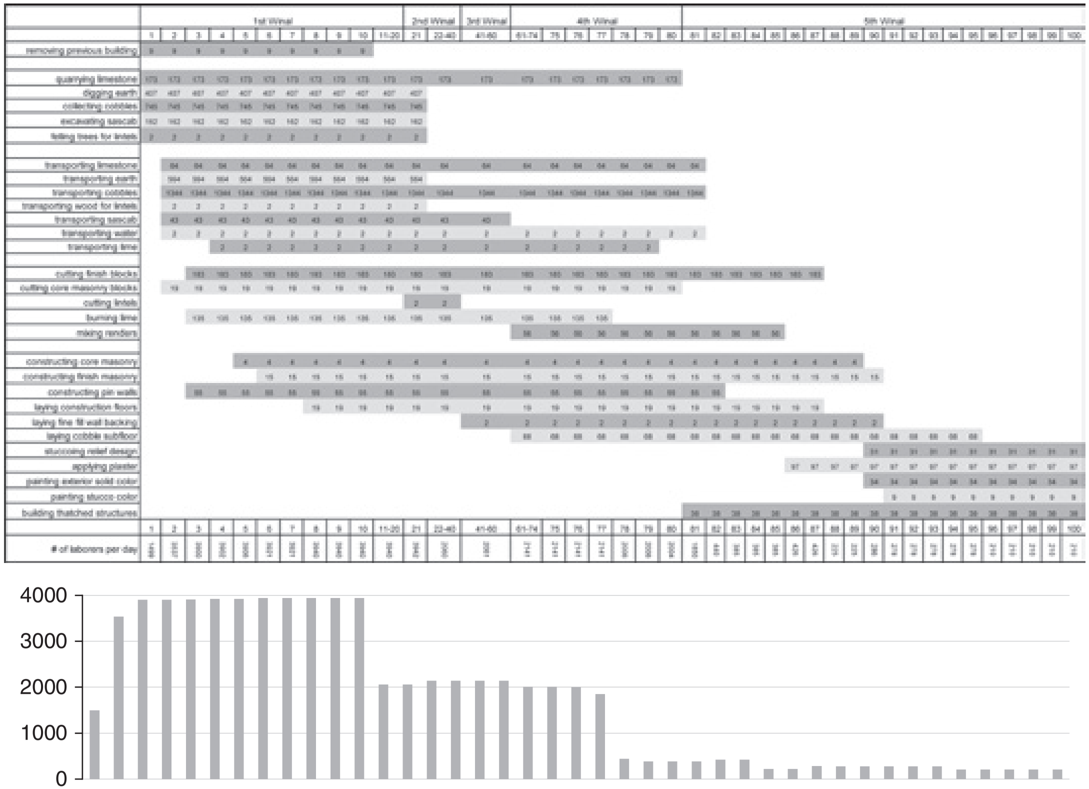

Figure 10.5 El Castillo Period 2b wholesale schedule visualization with labor bar chart

(Sharer and Traxler 2006) as another component for task scheduling. After totaling the number of laborers "on site" over each day, the bar chart at the bottom of Figure 10.5 visualizes fluctuations in total crew size, showing that it is not consistent but necessarily decreases over the course of a project (see also Abrams and Bolland 1999). This type of model offers a more complex view of labor and the dynamics of construction than wholesale figures.

Segmented feature analysis

Table 10.1 and Figure 10.5 represent the person-day estimates for the compiled features of Period 2b, including all three substructural platforms, all components of Structure A-6-3rd, and pole-and-thatch structures of the southern courtyards (see Figure 10.3). As such, this wholesale scheduled model conflates the construction process, simulating that Uck 2 Platform would be built at the same time as the roof of Structure A-6-3rd. Obviously, that is logistically impossible.

Segmented feature analysis incorporates the logistical progression of a construction project into the model, whereby features at the base of an architectural composition are built (and/or constructed to a certain point) prior to the initiation of any features that must be supported by the former. VARch allows for detailed projections of construction sequencing, as it requires consideration of superposition and how distinct features interface. Thus, the reverse engineering required of VARch is crucial for accurate and realistic reverse bookkeeping (energetic) results.

In the case of El Castillo Period 2b, Uck 2 Platform would have been built before Uck 1 and the latter before Lopez. Further, all three of these major platforms would have been constructed before the A-6-3rd substructures could have been initiated. There certainly could have been overlap whereby masons constructed the primary masonry components of Uck 2 Platform up to the desired height and laid an intermediate construction floor, then laid out the extents of Uck 1 Platform prior to laying the formal floor or plastering Uck 2. However, none of the assembly tasks for the A-6-3rd superstructure could have commenced prior to the nearly complete construction of the uppermost Sky Platform substructure (and by extension the lower two platforms). This sequence implies that masons constructing the walls and core of Uck 2 Platform could have moved onto that of Uck 1 while a small contingent remained to seal and protect Uck 2 with surface renders. As an alternative, plastering and finish work could have been relegated to the end of the construction period when all laborers but specialists were released from the efforts. Abrams and Bolland (1999, 279) mention evidence to suggest that plastering of Structure 10L-22 occurred across the entire building at one time. Whether such practices would translate to very large-scale substructures is uncertain.

Table 10.2 provides simulated laborer totals for each segment (or feature) of Period 2b construction. I conducted this first segmented analysis using the

Table 10.2 Scheduled and segmented model of El Castillo Period 2b using standard 100-day timing. P = persons; D = days

Features	*Uck 2 PF*		*Uck 1 PF*		*Lopez 2nd PF*		*A-6-3rd substr. Moon PF*		*A-6-3rd substr. Cloud PF*		*A-6-3rd substr. Sky PF*		*A-6-3rd superstr. Plinth*		*A-6-3rd superstr. Walls*		*A-6-3rd superstr. Roof*		*A-6-3rd superstr. Benches*	
Operations & tasks	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D
REMOVAL																				
removing previous building	33	3																		
PROCUREMENT																				
quarrying limestone	95	23	99	28	65	9	266	7	381	4	354	3	652	1	736	2	579	3	557	0.1
digging earth	460	6	485	7	426	2	366	2	227	1	288	0.8	25	0.2	25	0.6	42	1	108	0.04
collecting cobbles	854	6	883	7	771	2	650	2	484	1	508	0.8	34	0.2	34	0.6	56	1	145	0.04
excavating sascab	247	6	183	7	4	2	136	2	162	1	105	0.8	39	0.2	44	0.6	35	1	33	0.04
felling trees for lintels															32	0.6				
TRANSPORT																				
transporting limestone	35	23	36	28	24	9	98	7	140	4	130	3	240	0.7	271	2	213	3	205	0.1
transporting earth	638	6	672	7	591	2	508	2	314	1	399	0.8	35	0.2	35	0.6	58	0.7	149	0.04
transporting cobbles	1,540	23	1,593	28	1,391	9	1,173	7	873	4	917	3	61	0.7	61	2	102	3	261	0.1
transporting wood for lintels															7	0.6				
transporting sascab	66	17	49	21	2	7	36	5	43	3	28	2	10	0.5	12	2	9	2	9	0.1
transporting water	2	23	2	28	2	9	2	7	2	4	2	3	2	0.7	2	2	2	3	2	0.1
Transporting lime	2	22	2	26	3	9	2	6	3	4	3	3	6	0.6	4	2	7	2	6	0.1
MANUFACTURE																				
cutting finish blocks	116	24	101	30	66	10	272	7	389	5	362	3	666	0.7	752	3	592	3	569	0.2
cutting core masonry blocks	12	23	11	28	7	9	29	7	41	4	38	3	71	0.7	80	2	63	3	60	0.1
cutting lintels															35	0.6				
burning (and slaking) lime	68	22	57	26	257	9	150	6	211	4	226	3	467	0.6	343	2	554	2	482	0.1

(*Continued*)

Table 10.2 Continued

Features	*Uck 2 PF*		*Uck 1 PF*		*Lopez 2nd PF*		*A-6-3rd substr. Moon PF*		*A-6-3rd substr. Cloud PF*		*A-6-3rd substr. Sky PF*		*A-6-3rd superstr. Plinth*		*A-6-3rd superstr. Walls*		*A-6-3rd superstr. Roof*		*A-6-3rd superstr. Benches*	
mixing renders	31	23	26	28	87	9	69	7	98	4	101	3	202	0.7	169	2	185	3	199	0.1
ASSEMBLY																				
constructing core masonry	3	24	2	30	2	10	7	7	10	5	9	3	16	0.7	19	3	15	3	14	0.2
constructing finish masonry	9	24	8	30	5	10	22	7	32	5	29	3	54	0.7	61	3	48	3	46	0.2
constructing pin walls	65	23	64	28	55	9	44	7	49	4	33	3								
laying construction floors	30	23	22	28			15	7	17	4	10	3								
laying fine fill wall backing	2	14	2	17	2	6	3	4	5	3	4	2	8	0.4	9	1	7	2	7	0.1
laying cobble subfloor	23	4	17	5	355	2	41	1	52	0.8	96	0.6	254	0.1			69	0.5		
stuccoing relief design																	965	0.3		
applying plaster	43	4	35	5	339	2	88	1	121	0.8	156	0.6	359	0.1	141	0.4	175	0.5	11	1
painting exterior solid color	15	3	12	3	118	1	31	0.9	42	0.5	54	0.4	125	0.1	49	0.3	61	0.3	3	1
painting stucco color																	283	0.3		
building thatched structures					333	2														
LABORER TOTALS	**4,243**	**29**	**4,269**	**35**	**3,672**	**11**	**3,776**	**9**	**3,378**	**5**	**3,443**	**4**	**2,376**	**1**	**2,553**	**3**	**2,373**	**3**	**2,647**	**0.2**

100-day building period unit so that it may be comparable to the wholesale projection of 2,100 laborers. While more nuanced and logistically accurate than that above, upon close consideration this model is less than feasible. It involves very short periods of time for constructing the A-6-3rd superstructure. For example, all tasks to construct the large masonry benches would have to be completed within hours. Indeed, over 500 block cutters would have to work shoulder to shoulder for four hours to produce enough finished blocks. Looking to the estimate of 46 assembly masons, this would require teams of four masons installing finish masonry for each of the twelve benches simultaneously over only four hours. “Space availability” should be a concern when considering labor organization (Abrams and Bolland 1999, 285). In the cramped, nested rooms at the top of a massive acropolis, this scenario would not lend itself to productive outputs or general safety. Projects incorporating so many features must have exceeded 100 days.

Project duration and timing alternatives

The standard 100-day project duration is based on the seasonality of the Maya tropics. Abrams (1994) suggests that the main dry season, spanning about 100 days, would be the most reasonable time of year to conduct public building to avoid heavy rains and to coincide with the low period of agricultural demands. In considering this further, compilation of multiple sources on agricultural cycles in the Maya region suggests that agricultural demands are in fact comparatively high during the main dry season (see Figure 10.6). If many farmers were away from their *milpas* or terraces during that time,

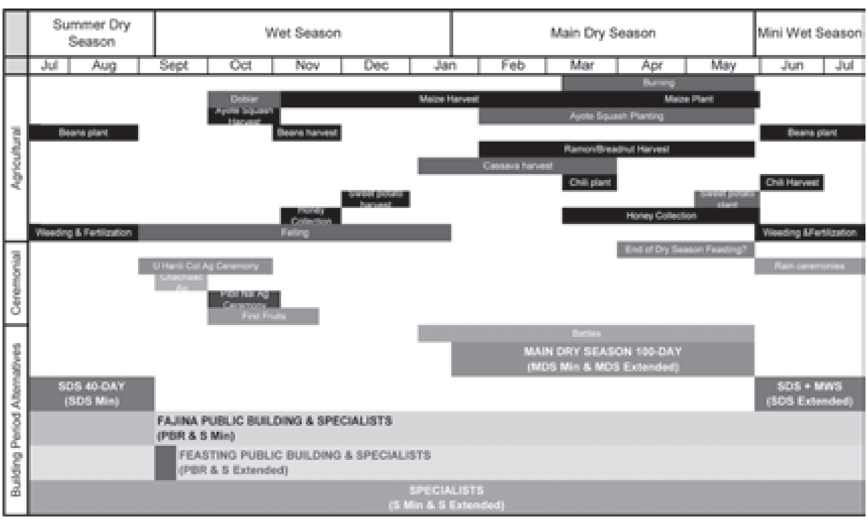

Figure 10.6 Calendar of agricultural periods, festive events, and architectural energetics timing alternatives used in this study

there may be serious productivity repercussions. Due to these findings, I developed a series of construction timing alternatives, which implicate distinct building period lengths (see Figure 10.6), to address various options for the annual scheduling of public building activities. These options also address the realistic possibility that timing and building duration likely fluctuated from year to year and transformed over the long-term, e.g. from the Preclassic to the Classic period.

Several scholars have problematized the issue of project duration in their studies, although alternatives are often limited (Abrams 1994; Abrams and Bolland 1999, 284; Blitz and Livingood 2004; Erasmus 1965; Murakami 2015; Rosenswig and Burger 2012, 10–11; Sidrys 1978). Erasmus (1965, 283, 296–297) discusses 40-day and 80-day alternatives for his case study that included all structures at Uxmal, Yucatán, Mexico. Indeed, he also outlined a scenario taking the full 250-year history of Uxmal into account, considering it as the meta-project duration for all building construction. Murakami (2015) projected 30-day, 60-day, and 100-day annual building period alternatives. In addition, Murakami (2015) considered multi-season project durations, determining that no building project would exceed ten years in total length at Teotihuacan.

To expand upon these previous studies, I consider eight alternatives of timing and project duration in pairs of minimum and extended length scenarios (see Figure 10.6). The main dry season minimum (MDS min) equates to Abrams' (1994) standard 100-day building period over one season. The main dry season extended (MDS ext) alternative involves building over multiple seasons of 100 days each. As a straightforward example of this alternative, Table 10.3 offers a view of labor organization for the construction of El Castillo Period 2b features over the course of ten MDS with a sequence of constructing the major platforms (seasons 1–6) to the substructural platforms of Structure A-6-3rd (seasons 7–9) to the superstructure itself (season 10). This alternative offers a much more feasible simulation of both construction and labor logistics for the period in which the most monumental construction efforts were undertaken at El Castillo.

I also consider a shorter duration model focused on the "short summer dry season" (Schele and Friedel 1990, 62) minimum (SDS min) representing 40 days (or two 20-day *winals*) of relatively low agricultural demand. I do not directly model a summer dry season extended alternative but I view it as a flexible option allowing for on-again, off-again building episodes cobbled together during downtime over multiple SDS and mini wet seasons (see Figure 10.6; McCurdy 2016, 305–311).

Another distinct alternative is what I refer to as public building ritual and specialists minimum (PBR & S min) that reflects a model of public participation in ritualized building activities over the 40-day SDS period and full-time specialists working to complete the project over the rest of the year. This is based on modern Maya community labor practices, called *fajina* (Redfield and Villa Rojas 1934; also Carballo 2013; Danziger 1996),

Table 10.3 Scheduled and segmented model of El Castillo Period 2b MDS extended ten season simulation. Laborer totals reflect most possible laborers (using schedule to determine which tasks would be conducted simultaneously)

Seasons	*1–2: Uck 2 PF*		*3–4: Uck 1 PF*		*5–6: Lopez PF*		*7: Moon PF*		*8: Cloud PF*		*9: Sky PF*		*10: A-6-3rd plinth*		*10: A-6-3rd walls & lintels*		*10: A-6-3rd roof & frieze*		*10: A-6-3rd benches*	
Operations & tasks	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D
REMOVAL																				
removing previous building	9	10																		
PROCUREMENT																				
quarrying limestone	14	80	17	80	4	80	23	80	20	80	14	80	47	9	53	33	42	36	40	2
digging earth	66	20	84	20	24	20	31	20	12	20	11	20	2	2	2	8	3	9	8	0.5
collecting cobbles	122	20	153	20	44	20	56	20	26	20	20	20	2	2	2	8	4	9	11	0.5
excavating sascab	35	20	32	20	2	20	12	20	9	20	4	20	3	2	3	8	3	9	2	0.5
felling trees for lintels															2	8				
TRANSPORT																				
transporting limestone	5	80	6	80	2	80	8	80	7	80	5	80	17	9	20	33	15	36	15	2
transporting earth	92	20	117	20	34	20	44	20	17	20	16	20	3	2	3	8	4	9	11	0.5
transporting cobbles	221	80	277	80	80	80	101	80	47	80	36	80	4	9	4	33	7	36	19	2
transporting wood for lintels															2	8				
transporting sascab	9	60	8	60	2	60	3	60	2	60	2	60	2	7	2	25	2	27	2	1
transporting water	2	80	2	80	2	80	2	80	2	80	2	80	2	9	2	33	2	36	2	2
transporting lime	2	75	2	75	2	75	2	75	2	75	2	75	2	9	2	31	2	34	2	2
MANUFACTURE																				
cutting finish blocks	17	85	18	85	4	85	23	85	21	85	14	85	48	10	55	35	43	38	41	2
cutting core masonry blocks	2	80	2	80	2	80	2	80	2	80	2	80	5	9	6	33	5	36	4	2
cutting lintels															3	8				

(*Continued*)

Table 10.3 Continued

Seasons	*1–2: Uck 2 PF*		*3–4: Uck 1 PF*		*5–6: Lopez PF*		*7: Moon PF*		*8: Cloud PF*		*9: Sky PF*		*10: A-6-3rd plinth*		*10: A-6-3rd walls & lintels*		*10: A-6-3rd roof & frieze*		*10: A-6-3rd benches*	
burning (and slaking) lime	10	75	10	75	15	75	13	75	11	75	9	75	34	9	25	31	40	34	35	2
mixing renders	4	80	5	80	5	80	6	80	5	80	4	80	15	9	12	33	13	36	14	2
ASSEMBLY																				
constructing core masonry	2	85	2	85	2	85	2	85	2	85	2	85	2	10	2	35	2	38	2	2
constructing finish masonry	2	85	2	85	2	85	2	85	2	85	2	85	4	10	4	35	3	38	3	2
constructing pin walls	9	80	11	80	3	80	4	80	3	80	2	80								
laying construction floors	4	80	4	80		80	2	80	2	80	2	80								
laying fine fill wall backing	2	50	2	50	2	50	2	50	2	50	2	50	2	6	2	21	2	22	2	1
laying cobble subfloor	3	15	3	15	20	15	3	15	3	15	4	15	18	2			5	7		
stuccoing relief design																	45	7		
applying plaster	12	15	12	15	39	15	8	15	6	15	6	15	26	2	10	6	13	7	31	0.4
painting exterior solid color	4	10	4	10	13	10	3	10	2	10	2	10	9	1	4	4	4	4	11	0.2
painting stucco color																	17	5		
building thatched structures					38	20														
LABORER TOTALS	**614**		**747**		**224**		**330**		**187**		**145**		**178**	**12**	**193**	**41**	**178**	**45**	**198**	**2.5**

which may have ancient roots (McCurdy 2016, 175–181). The PBR & S extended models simulate scenarios whereby ritualized public participation occurs as an aspect of feasting events (over one or several days) and specialists work over extended periods of time prior to and after feasting to complete features.

The final two alternatives reflect full-time specialist labor. These include the specialist minimum (S min) alternative that simulates the time it would take a standard cohort of 120 specialists to construct the features in question and the specialist extended (S ext) alternative that simulates long-term specialist project durations projected over half of each entire period length (e.g. 12.5 years of the 25-year span of Period 2b). These specialist models follow an annual building period of 340 days in which specialists would devote all productive time to construction with a break period during the five *Wayeb* days (Sharer and Traxler 2006) and one *winal* of 20 days that may be dedicated to personal and/or public ritual activities. Based on each of these timing alternatives, I can project a detailed project schedule and schedules for each season or segment of building.

In my comprehensive analysis of El Castillo, I modeled scheduled and segmented labor projections using each timing alternative for each period. For interpretive discussions, I emphasize one timing alternative for each period to consider the potential sociopolitical and economic implications relevant to our understanding of Xunantunich's cultural history (see Table 10.4). I chose alternatives that I consider particularly feasible or interesting in view of current understandings of social change and political dynamics at Xunantunich. For example, for the Middle Preclassic (Period 1a), I present a PBR & S extended model whereby early political leaders may have organized feasting events to attract labor to the newly established center (see Brown and Garber 2005; Rathje 2002). Rafael Sara-Lafosse (2006) suggests that construction activities such as fill deposition may have directly connected to post-feasting deposition of waste materials. Such connections and alternatives can broaden our conceptualization of who these laborers were, the ways they related to elite coordinators, and the meaning of construction events and labor participation.

For Period 1b, I emphasize building episodes conducted in the SDS over several years. With increases in population size and density evident in Late Classic settlement data (Neff 2010), I emphasize longer MDS building periods for both Period 2a early Samal and Period 2b mid-Samal. For Period 2c late Samal, I concentrate on a *fajina* public building ritual event (PBR & S min) alternative to simulate the possibility that public obligation to monumental construction could decrease in a time of relative sociopolitical prosperity (in contrast to standard labor control models). In the beginning of the Hats' Chaak or Period 3a, I project that construction durations reverted back to the longer MDS alternative. At the apogee of Xunantunich's sociopolitical status within its regional context in the mid-Hats' Chaak phase, I emphasize the possibility that fully specialized cohorts of builders could

Table 10.4 Impact assessments for emphasized timing alternatives for all El Castillo periods

Period	*Emphasized timing alternative*	*% of Hh*	*% of total Pop*	*% of ATB*	*Frequency*	*% of Hh*	*% of total Pop*	*% of ATB*	*Frequency*
		Minimum participation				*Maximum participation*			
1a Middle Preclassic	PBR & S Ext	300%	60%	0.30%	one time	150%	30%	0.30%	two times
1b Late Preclassic	SDS Ext	100%	20%	5%	one time	73%	15%	11%	two times
2a Late Classic Early Samal	MDS Ext	17%	3%	23%	three times	3%	0.6%	23%	nine times
2b Late Classic Mid Samal	MDS Ext	110%	22%	12%	one time	11%	2%	12%	ten times
2c Late Classic Late Samal	PBR & S Min	20%	4%	5%	one time	15%	3%	11%	two times
3a Late Classic Early Hats' Chaak	MDS Ext	23%	5%	8%	one time	2%	0.4%	8%	twenty times
3b Late Classic Mid Hats' Chaak	S Min/Ext	1%	0%	100%	full time				
4a Late Classic Late Hats' Chaak	PBR & S Ext	39%	8%	1%	one time	13%	3%	1%	seven times
4b Terminal Classic Tsak'	SDS Ext	21%	4%	8%	one time	7%	1%	8%	three times

have completed Period 3b construction (which included a number of isolated superstructure additions). In the waning moments of the Late Classic florescence at Xunantunich (Period 4a), I project that a series of "throwback" feasting events (PBR & S ext) may have been organized to reintegrate the surrounding communities. Finally, a series of SDS building periods in the Terminal Classic (Period 4b) would have allotted plenty of time for the small additions made during this period. There are other plausible alternatives for each period that can be interpretively explored in the future based on the comprehensive analysis conducted as part of this project. I return to the emphasized projections and consider their implications as a component of impact analysis below.

Labor expanded

Refining the complexity of architectural energetic results as described above leads to nuanced models of labor organization. I suggest a nested system of labor projections to include global, regional, and local scales (see Figure 10.7). Global labor models represent the total labor force and correspond to the types of labor estimates I have discussed thus far. To reach farther into the laborer perspective, regional labor projections involve simulations of supervision and management.

I base one set of regional projections on what Greg Johnson (1982) labels as "scalar stress" in group collaboration. Johnson's model suggests that one supervisor can effectively oversee six plus or minus two laborers without the development of communication and/or coordination stresses. Johnson (1982, 410) also suggests that these principles of scalar stress affect additional levels of management or what he refers to as the "span of control" whereby supervisors are overseen by managers with the same scalar stress limits. I choose the managerial terms of supervisor, manager, and master to distinguish between each level and relate to common labels such as "master builder." One manager can effectively oversee six plus or minus two supervisors. To scale up, one master can oversee six plus or minus two managers. Based on this approach, I project scalar stress maximum, average, and minimum models for supervisory cohorts based on global labor estimates (see Figure 10.7).

We can apply these scalar stress principles to realistic labor projections such as those for the construction of the uppermost substructure (Sky Platform) of A-6-3rd during Season 9 MDS ext alternative for Period 2b (see Figure 10.7). Looking to the regional labor projections at the bottom of Figure 10.7, on Day 1 of the project, one master oversees two managers, who in turn each oversee four or five supervisors and workgroups. On Day 2, more workgroups come on board. Figure 10.8 offers a distinct way to visualize the labor organization of Day 2, modeled on social network mapping. Based on the distribution of tasks and workgroup size (to not exceed the scalar stress maximum of eight laborers per group), we

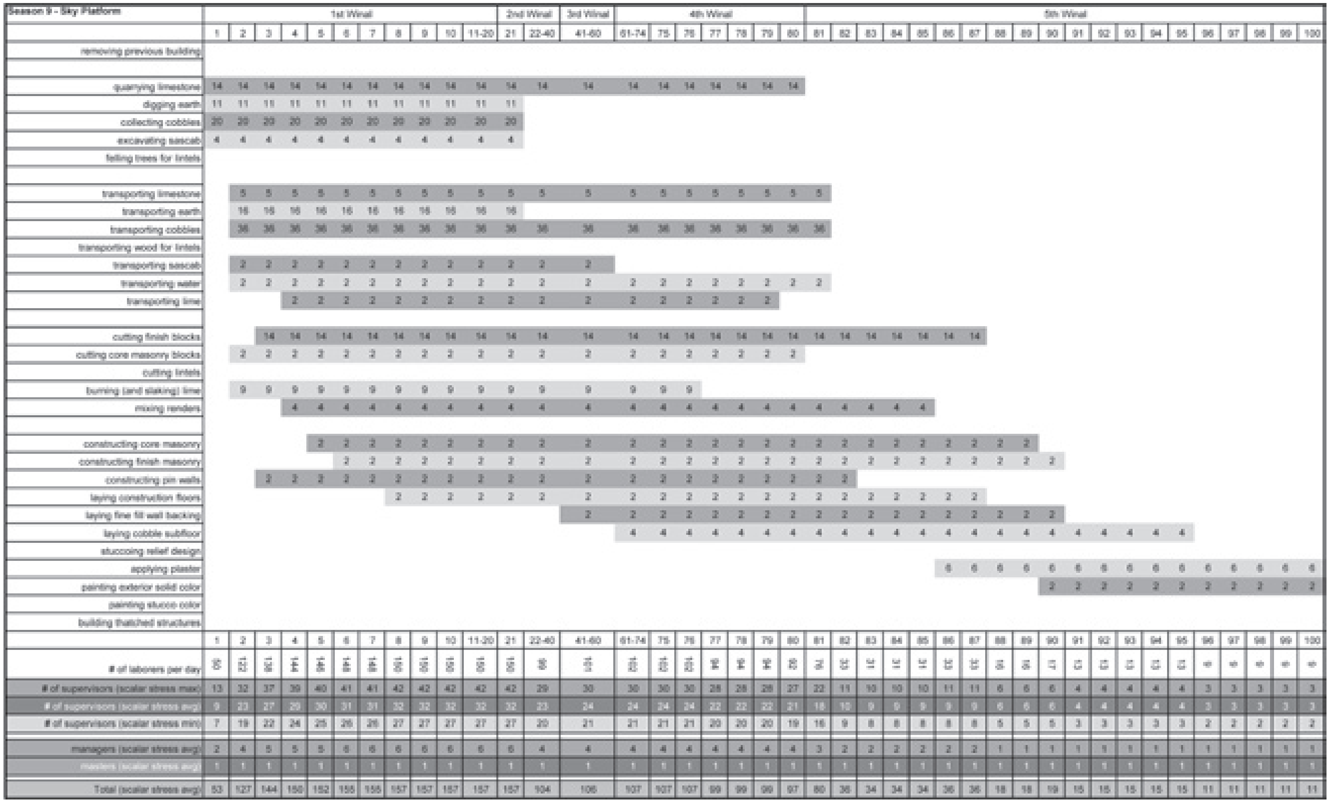

Figure 10.7 El Castillo Period 2b MDS ext Season 9 labor chart with global, regional, and local labor estimates (ss = scalar stress)

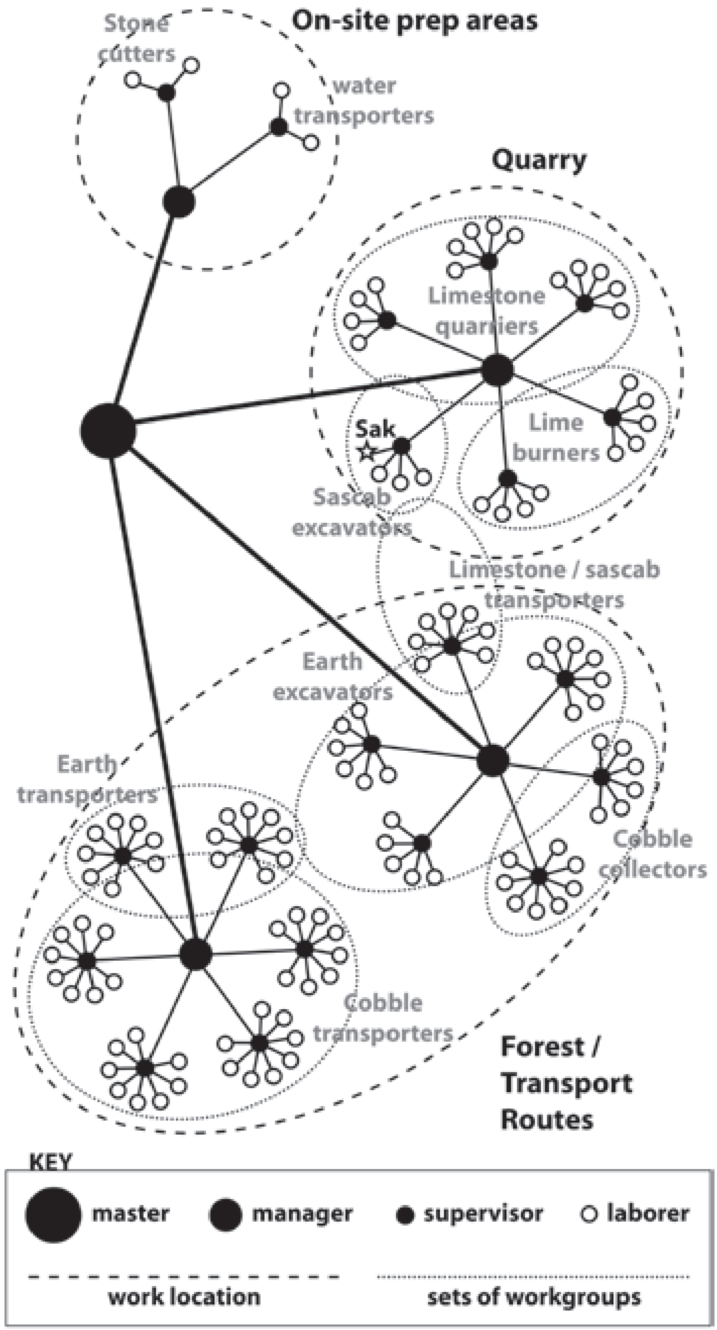

Figure 10.8 Social network visualization of Day 2 (indicated by the arrow on Figure 10.7) labor data from Figure 10.7

can consider distinct managerial zones and spatial organization whereby laborers working at the quarry are under the purview of a single manager. Transporters and those collecting materials from the forest work in collaboration. Lastly, a small on-site crew works until more laborers come on board to start building walls. Such simulations are interesting as conduits to consider the relationships among managers, supervisors, and workgroups within proximity to each other and/or those that would collaborate through interdependent tasks.

This regional perspective can lead to what I refer to as the local scale of labor and considerations of workgroup dynamics. For example, we can consider the relationships between the workgroups stationed at the quarry (working on extracting limestone, collecting *sascab* [eroded powdery limestone], and burning for lime) with those more mobile laborers transporting these materials to the building site. With seven transporters and 27 laborers working across the quarry (see Figure 10.8), there is a potential for 189 personal relationships between the members of each workgroup. These relationships could be preexisting, perhaps based on familial ties or friendships, or newly developed as a result of collaborative participation in public building.

The local scale also can lead to considerations of individual laborers. For example, the star symbol in Figure 10.8 represents one individual laborer within the global labor force. With an interest in humanizing ancient laborers as much as possible, I suggest we call this laborer Sak (meaning "white" in Yucatec Mayan). He is part of a workgroup excavating white *sascab* near and within the limestone quarry. He may have been assigned to that workgroup because he has some experience with the material. He works to extract *sascab* during this early stage in the project and eventually, he may become part of the transport crews that bring the excavated *sascab* to the building site. Once all the material is on site, he may join the crews mixing mortars (that contain a good deal of *sascab*). Sak's tenure on site ends once this crew produces enough mortar to satisfy the needs of the masons finishing wall construction.

In terms of individual effort, Sak's 85-day contribution represents a little more than 1% of the total person-day season effort to build the final substructure that will support the new monumental temple superstructure at the center of El Castillo acropolis. A detailed and scalar laborer perspective allows for such consideration of individual contribution, lest we forget that individuals actually contributed to building monumental structures. Further, this scalar view broadens what that monumental platform can reflect about the past, to include Sak's and his fellow laborers' lived experience, motivations in participation, and even feelings about the buildings that result as a consequence of their individual effort.

Impact of participation

A final extension to energetics and labor analysis explored here involves impact assessments. I consider the impact that participating in public

building would have on the lives of laborers, in the running of households, and from a total social perspective (see also Brysbaert 2017). To conduct impact assessments, I compare all labor models to population estimates for the settlement areas around Xunantunich over time (see McCurdy 2016, Tables 8.1 and 11.1). As with the labor projections described previously, I focus on the emphasized timing alternatives for detailed analysis for each period.

Table 10.4 presents a chronology of impact assessments including: 1) period and emphasized timing alternative; 2) the percentage of households involved in construction (where percentages exceed 100%, more than one member of each household would be involved); 3) the percentage of the total population involved; 4) the percentage of annual time budget (ATB, measured in 365 days; after Redfield and Villa Rojas 1934, 80) that contribution to construction entails; 5) the frequency at which individuals would participate in construction events (based on the timing alternative; this could be over multiple years depending on the timing). Each scenario is provided in terms of minimum and maximum participation derived from retained versus replaced labor models (McCurdy 2016). Essentially, minimum participation refers to potential practices of laborer replacement whereby new community members would fold into laborer populations for each set of tasks (i.e. involving more people in construction over a minimum personal investment). Maximum participation refers to simulations of labor recruitment whereby laborers are retained over the course of a project (i.e. moved around from task to task until their effectiveness in terms of experience or expertise is exhausted). This implicates practices focused on consistent workgroup membership or maximum individual investments in each project.

For example, in the case of Middle Preclassic feasting (Period 1a), at minimum 60% of the population (three members of each household) would participate in the work feast but only for one day out of their entire productive year (0.3% of their annual time budget). At maximum, 30% of the population may participate in a feasting event in two consecutive years. To return to mid-Samal Period 2b, the ten-season MDS extended simulation implicates, at minimum, one member of every household and an additional member of 10% of households participating over 45 days (12% of their annual time budget) once in the ten-year period. At maximum, one member of 11% of households (or 2% of the total population) would contribute over 45 days every season for ten years.

To return to the local scale of labor, these householders would be people like Sak, the *sascab* excavator and render mixer considered above. When crews of at most 750 or as few as 200 were working in the quarries, across the forests, and at the building sites over the years (see Table 10.3), the other 14,000 members of the population would have a view of the spectacle of public building from residential communities like San Lorenzo to the north or Chan to the southeast. The construction would have been a topic

of conversation, a spot on the horizon to ponder, and perhaps a performance to recognize as cosmologically sacred (McCurdy 2016). Kids may have missed their fathers or mothers while they were away. Such intimate considerations of monumental building labor inspired colleagues and me to produce an archaeologically accurate and trilingual children's book exploring this topic and visualizing change at El Castillo as a community outreach initiative (Batty et al. 2016).

As a tie to elite labor control arguments, the most impactful estimate (excluding those involving full-time specialists) comes from Period 2a in which between 0.6% and 3% of the population were impacted for 23% of their annual time budget. Such an amount of time devoted to public building could impinge upon agricultural demands such as those of maize planting and harvest (estimated to amount to 56% of annual time budgets, after Redfield and Villa Rojas [1934]). This simulation may represent a moderately exploitative labor system that hindered personal agricultural productivity.

Generally, these alternatives indicate that public building participation, or labor control, was relatively lax or not necessarily burdensome within the Xunantunich community. Thus, arguments immediately assuming strong corvée systems of forced tribute conscription do not necessarily apply, even at the sociopolitical apogee of the Late Classic Maya (see also Webster and Kirker 1995). Indeed, as Robin and colleagues (2010) suggest, the communities around Xunantunich appear to be relatively autonomous and independent from the political ebb-and-flow that is evidenced at the elite center. Communities around the center were certainly involved in its development, some more than others perhaps, but that does not mean that their lives were controlled by it.

Conclusions

The laborer perspective applied to El Castillo demonstrates the utility of alternative and complementary approaches to those focused on elites and labor control. As such, I find it important to extend statements such as the following from Richard Leventhal (2010, 79–80), the principal investigator of Xunantunich during the 1990s; he states that "This regal-ritual complex is the most significant construction at [Xunantunich] for understanding shifting power relations between elite families living at the site and the rulers' relations with external leaders." To "people" this monument, Leventhal's statement about the significance of El Castillo could be expanded beyond "elite families" and "external leaders" to include how the people of communities surrounding Xunantunich contributed to the creation of monumental features of public significance.

Analytically, I emphasize that architectural energetics can be expanded by critically considering the scale of monumentality under investigation, scheduling logistics, construction sequences and segmentation, the timing

and duration of building periods (including sets of alternatives), scalar views of labor organization to include small-scale individual effort, and the impacts that participation in building had on individual laborers and their households. Beyond person-day estimates, who were the persons that put in the days? How did those days fit into their lives as agentive people?

Interpretively, I emphasize that all investigations of monumental structures and complexes can incorporate more nuanced means to understand construction labor and its sociopolitical implications. Oftentimes, interpretations of excessive elite control and exploitation of corvée masses are easy to make because we "hear" so much more from the elites and their propaganda. I suggest flipping the perspective to consider laborers as people with options, preferences, relationships, and motivations. What would be the implications if some of the households in Period 2b refused to participate in one of the building seasons? Robin and colleagues (2010 citing Farriss 1984) suggest that community members around Xunantunich "voted with their feet" by moving across the landscape to distinct settlement areas over time. What if they also voted with their hands? In this way, we can broaden the sometimes constricted view of monumentality to include what monumental complexes like El Castillo reveal about communities and the people that quarried the stone, built the walls, and applied the plaster.

Acknowledgments

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11 A construction management approach to building the monumental adobe ciudadelas at Chan Chan, Peru

Richard L. Smailes

Construction project management analyses

Construction of modern architectural and engineering works relies on a sophisticated array of project planning, management, and simulation systems to generate multiple, dynamic building scenarios. These techniques can be productively employed in archaeological analysis of ancient monuments. The aim of this chapter is to demonstrate their broad applicability and establish a methodology of these analytical systems to the testing of archaeological hypotheses concerning scale of construction, organization of labor, and complexity of social organization.

Construction industry practices such as estimating and scheduling routinely calculate the estimated cost and duration of projects. Construction estimating is adept at determining the resource requirements to build a structure in terms of labor and material to calculate an estimated cost. In terms of time or duration of a project, critical path method (CPM) scheduling allows the modeling and comparing of multiple construction scenarios by simulating various construction strategies involving the deployment of resources. While uncertainty is high in an archaeological context the use of probabilistic evaluation and review technique (PERT) is used to quantify that uncertainty in estimating and scheduling. These construction industry techniques are applied to the Ciudadela Rivero, in Chan Chan, Peru built by the Chimu around 1400 CE.

Knowing *how much* labor was invested in a project is only a partial use of the data. If the goal of archaeology is to elucidate the dynamics of a society, then we need accurate information concerning *how* that labor was deployed and *how long* the construction processes may have taken. The need is for a method to incorporate the static data from labor estimates into a system to simulate the dynamics of the construction process. Social and organizational theories can then be compared and evaluated in a dynamic context.

This retrospective approach to the construction process, and integration of the design, estimating, and scheduling functions, produces a powerful means of quantitative analysis. The design defines what to build. The estimate represents its labor cost. The schedule simulates the construction strategy and labor distribution, in addition to allowing for the calculation

of project duration. This investigation takes the point of view of the contractor operating within the social structure and technology available during the construction of the ciudadelas at Chan Chan. The subsequent discussion summarizes the research that uses contemporary project management tools and techniques in the context of constructing Ciudadela Rivero (Smailes 2000).

Construction labor quantification

The standard construction industry estimating process consists of: 1) determining the quantity of material (quantity survey); 2) applying productivity rates to establish the number of person-hours, then multiplying by the pay rates to establish the labor cost (estimating). In an archaeological context, productivity rates (or work rates) are often derived from results of direct on-site repetitive experiments or by adjustment of existing data to meet the situation. While productivity rates in a commercial context are often treated as highly guarded proprietary information there is an abundance of data in modern construction estimating databases that can provide valuable input into quantitative analyses. However, these methods are deterministic in nature and rely on a single value for productivity for a given work operation. The present research refines and extends the method of architectural energetics by demonstrating techniques that account for uncertainty in the data that can produce statistically qualified labor estimates based on a range of productivity rates.

The process of calculating the labor investment represented in a project requires 1) defining the *scope of work*, and developing a *work breakdown structure*; 2) performing a *quantity survey* to determine the types and amounts of installed materials; 3) identifying and estimating *productivity* in the form of unit rates; 4) calculating the *project estimate* from the installed quantities and unit rates.

Construction scheduling

While quantifying labor does provide useful information, it also "emphasizes the passivity of architecture" (Moore 1996, 64). The resultant data are static. All that can be said for certain is that one structure required more labor than another or that the scale and complexity of architecture is a relative indicator of social organization. The problem is that the architecture is separated from its behavioral context. If we intend to study the past in dynamic terms, we need some means to consider the data in dynamic constructs (Bleed 1991, 19, 32). In short, quantifying labor expenditures is only part of the story. As Kaplan (1963, 401) states, "unless we can be more precise in our estimates of how these man-hours were distributed over time, any attempts to derive the size or character of political units from the size or number of structures in question is highly dubious."

Fortunately, the construction industry routinely uses methods to simulate multiple building processes that archaeologists can employ to estimate the time parameters of construction under various labor organization models. To gain insight into the dynamic processes involved in controlling labor, archaeologists, much like the potential owners of a building, need to know how much the structure cost and how long it took to build.

Critical path method (CPM) scheduling is a network-based modeling system used to evaluate a group of interrelated activities to simulate the time and resource aspects of a project. Logical relationships between activities determine the schedule within which activities can start and finish, their resource requirements, and the overall duration of the project. CPM permits evaluation and manipulation of the project plan in terms of lengths of time and efficient resource utilization by integrating activity data from the project estimate with the relationships from a logic diagram. It also facilitates "what-if" scenarios to simulate and evaluate multiple construction strategies, resource allocation, and utilization schemes. This application of CPM presents a versatile tool to dynamically model how resources *might have been used* within the context of prehistoric construction. These practical, problem-solving methods "fit well with the evolutionary interests of many modern archaeologists" (Bleed 1991, 19–20).

Thus far, estimating and CPM scheduling are deterministic and use a single estimate and duration derived from the most likely unit rates. By presuming no uncertainty in productivity, there is no accounting for variability. Nevertheless, uncertainty in productivity does exist since it is impossible to make precise correlations when estimating prehistoric construction. By using the program evaluation and review technique (PERT), unit rates and durations are represented by the *optimistic*, *pessimistic*, and *most likely* range of values calculated for each activity, and the effect of this uncertainty on the project's estimate and schedule is quantifiable in terms of probabilities (Hinze 2008, 313).

Estimating the overall duration of a project involves preparing logic diagrams to represent the project work plan, establishing crew sizes and activity durations, calculating a CPM schedule based on the logic, and performing probabilistic risk analysis to account for uncertainty. The case study for demonstrating these tools and techniques involves the construction of the compounds or ciudadelas at Chan Chan, Peru. A single storeroom building serves to illustrate the application of each step employed in the analysis. Then, the analysis is applied to Ciudadela Rivero in full.

The architecture of Chan Chan

Civilizations on the north coast of Peru have engaged in building monumental constructions for thousands of years. This area of Peru exhibits a unique geographic niche consisting of a narrow strip of one of the most arid deserts in the world, stretching 350 km along the coast. It is bordered on the west

by the Pacific Ocean, host to some of the most bountiful and productive marine resources in the world, and on the east by the Andes Mountains. Due to the lack of rainfall, the only sources of water along this desert strip are the rivers carrying runoff from the western slopes of the Andes causing control of land and water to be a critical element in the development of north coast societies. Yet even in this hostile environment, monumental building occurred early and often since pre-ceramic times (±2000 BCE). Prehistoric Andean societies exhibited the ability to muster a labor force capable of building sophisticated engineering and architectural projects. Hundreds of aqueducts, irrigation canals, mounds, pyramids, and compounds represent the tangible remains of these prolific builders.

The city of Chan Chan is in the Moche Valley and was the capital of the Chimor Empire during the period 900 to 1470 CE. With a society based upon divine kingship and nobility, the Chimu dominated the entire north coast until their abrupt end in defeat and incorporation into the Inca Empire (Rowe 1948, 42–46). Through their period of regional dominance and subsequent influence on the Incas, the Chimu played a vital role in the evolution of social complexity in the Andes.

Dominating the urban core of Chan Chan is an area containing ten monumental adobe enclosures called ciudadelas covering an area of 6 square km, while metropolitan Chan Chan encompasses 20 square km (Moseley 1975a, 219–220). Ciudadela Rivero, while the smallest of the compounds, is typical in layout (see Figure 11.1). The site also includes smaller elite adobe compounds, and barrios of cane and cobble; these domestic and

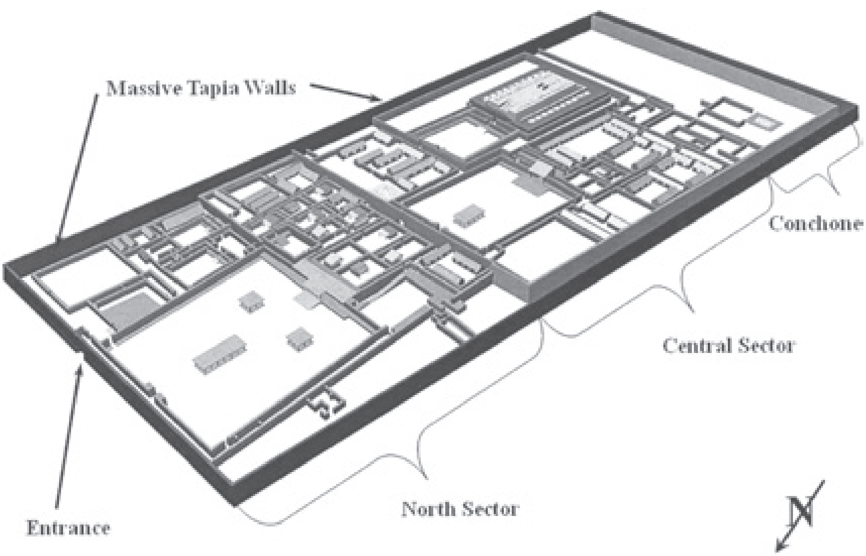

Figure 11.1 View of Ciudadela Rivero

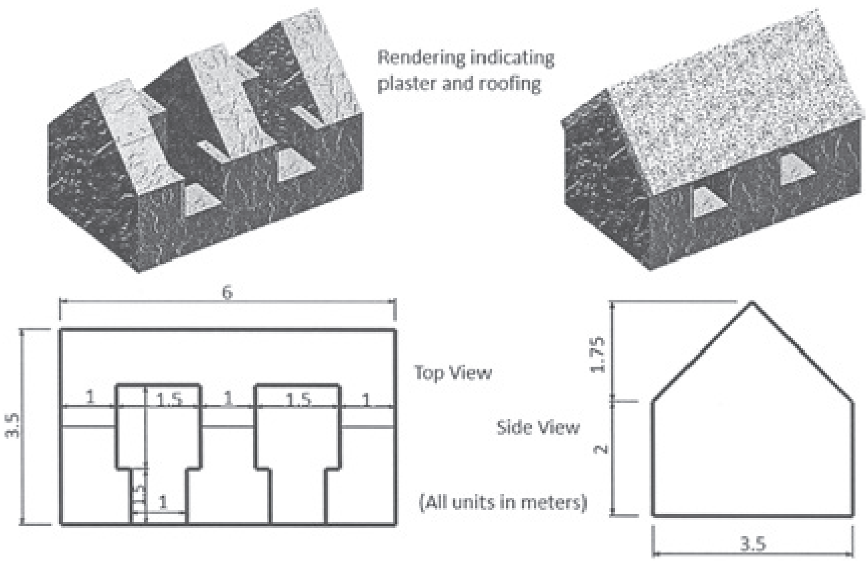

Figure 11.2 Typical storeroom at Chan Chan

craft oriented structures housed most of the sites' estimated 30,000 inhabitants (Moseley 1975a, 223; Topic 1990, 152; Topic and Moseley 1983, 157). Additionally, the site includes adobe mounds, walk-in wells, and sunken fields.

Typical storeroom

The generic two-bay storeroom, typical of Chimu construction at Chan Chan, is an adobe structure 3.5 m wide and 6 m long (see Figure 11.2). The walls are made of sun-dried bricks approximately 19 cm × 48 cm × 10 cm, with a 10 cm coating of mud plaster on all exposed surfaces, and a 5 cm thick layer of clay on the floor. The roof structure is made of two species of native bamboo, *cana de guayaquil* and *cana brava*. Beams of 10 cm diameter *cana de guayaquil* are bound to perpendicular layers of 3 cm diameter *cana brava*, and topped with a 5 cm layer of grass and mud.

Labor quantification

Scope of work

The sum of all deliverables that make up a project is the *scope of work*. Typically, modern plans and specifications serve to describe a structure explicitly in terms of material types, sizes, amounts, quality, and location in a project. A work breakdown structure (WBS) is a hierarchical

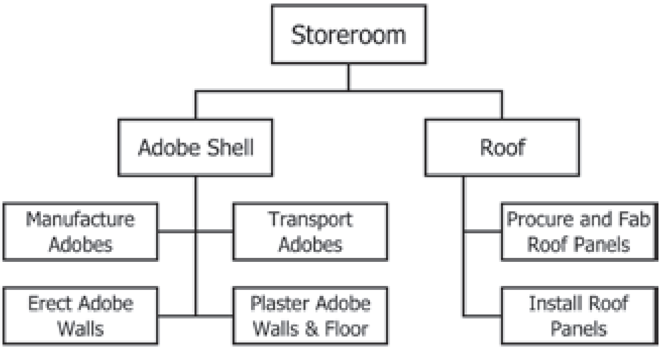

Figure 11.3 Work breakdown structure (WBS) for storeroom

representation of the scope of work. A WBS defines and organizes the project where each descending level divides and subdivides the work into an increasingly detailed definition of components culminating in discrete tasks or *activities*. The level of detail is subjective and is a function of the ability and desire to estimate quantities, costs, and time.

A simple WBS representing the storeroom (see Figure 11.3) consists of two major components: the adobe shell and the *cana* roof. Subsequently each component is subdivided into separate and distinct tasks. The construction of the adobe shell requires manufacturing the bricks and transporting them to the site, followed by their installation in the wall. The walls need to be plastered and the clay floor placed. To build the roof both *cana brava* and *guayaquil* must be gathered, fabricated into panels, and installed on the roof and plastered. These activities are discrete, quantifiable, and represent a unique place in time. The sum of these activities represents the total scope of work for the construction of the storeroom.

Quantity survey

The quantity of installed materials is the basis for determining the labor cost of each activity. The quantity survey delineates the measured quantities of material in a manner consistent with the activities, in the proper units of measure used for estimating. From the WBS, building an adobe wall involves manufacturing adobes, transporting them to the site, and installing them in the wall. Since the adobes vary in size, the common unit of measure for estimating the productivity of these activities is volume. For plastering and clay flooring the unit of measure is square meters and for the roof, the unit is based on a series of four 2.5 m × 3 m panels. Table 11.1 shows the detailed quantity survey of installed materials for the storeroom.

Table 11.1 Quantity survey of storeroom

Item description	*No.*	*Dimensions*			*Total quantity*
		Length	*Width*	*Height*	
STOREROOM					
Adobe walls – standard adobes 24 cm × 10 cm × 19 cm					
Front wall	1.0	6.0	1.0	2.00	12.00 m³
Less openings	–2.0	1.0	1.0	1.00	–2.00 m³
Rear wall	1.0	6.0	1.0	2.00	12.00 m³
Side walls	3.0	1.5	1.0	2.00	9.00 m³
3 Triangular gables/2	1.5	3.5	1.0	1.75	9.19 m³
Total volume of adobe walls					40.19 m³
Total number of adobes @ 172 adobes/m³					6912
Plaster walls – 10 cm					
Exterior					
Front wall	1.0	6.0		2.00	12.00 m²
Less openings	–2.0	1.0		1.00	–2.00 m²
Rear wall	1.0	6.0		2.00	12.00 m²
Side wall	3.0	1.5		2.00	9.00 m²
3 Triangular gables/2	1.5	3.5		1.75	9.19 m²
Interior					
Room	2.0	4.5		2.00	18.00 m²
Openings	2.0	3.0		1.00	6.00 m²
Total area of plastering					64.19 m²
Clay flooring – 5 cm					
Rooms	2.0	1.5		1.5	4.50 m²
Total area of clay flooring					4.50 m²
Roofing – cana					
Roof panels	4.0	3.0	2.5		30 m²
Total cana de guayaquil – 10 cm dia. @ 2m/m²					60 m
Total cana brava – 3 cm dia. @ 60 m/m²					1800 m

Productivity – unit rates

Productivity is the cost per unit of output measured in terms of person-hours, and is referred to as unit rates. The estimator's job is to develop and apply unit rates to the quantity survey to calculate the project estimate. One of the challenges of analyzing ancient construction is determining unit rates using the tools and techniques of the period. The development of productivity rates for ancient construction is often linked to field experiments designed to replicate ancient tasks. Unit cost data are often highly proprietary within the construction industry, but fortunately, data from field experiments performed by archaeologists are not and often provide valuable

statistics adaptable to the study site. Lacking direct experimental data, the best evidence of techniques is in the architecture itself and in building traditions passed down through generations. Often techniques that endure for generations are still in use making contemporary practitioners particularly helpful in this regard by providing a first-hand perspective unavailable from other sources.

Similar solutions to similar problems are prevalent worldwide and examinations of data across geographic boundaries should not be overlooked. Construction is not a wholly automated process and many of the work operations used in the past are still in use at present. Commercially published construction cost guides, compiled from years of sampling, contain productivity rates for a variety of manual operations. These rates provide a good approximation of the work required to complete a given task.

Lacking any other source material, an estimator mentally constructs the activity step-by-step, and based upon their best knowledge and experience predicts the productivity rate to produce a conceptual estimate. The degree of concern over weak data is relative to the activity's overall contribution to the whole. A *best guess* of an item of little importance has a negligible effect on the total project, while identifying critical areas of weak or missing data serves to guide future research in productive directions.

An appropriate and effective approach to estimating prehistoric construction is identifying the range of probable unit rates for each activity. Multiple sources of data are useful for bracketing the probable productivity rate in terms of high and low expectations. In this method, the *most likely* value represents work progressing as expected with normal progress under normal conditions. This is the rate most probable to occur and treated as deterministic in most analyses. However, conditions are not always ideal, and estimates are only that. To the contractor, this uncertainty represents an identifiable risk in terms of the probability of completing a project on time and within budget. Statistical modeling techniques such as PERT use a range of unit rates and perform thousands of iterations with the potential variables to calculate the probable ultimate cost based on the frequency of the outcomes. The *optimistic* estimate sets one end of the productivity range and assumes that the work proceeds with better than expected results, while the *pessimistic* estimate reflects poor productivity due to unforeseen or unusual difficulties. Unless statistical analyses are contemplated, only the *most likely* rates need to be derived.

The following paragraphs detail the development of these ranges of unit rates for significant items identified in the quantity survey. Each begins with a discussion of the construction techniques involved followed by the data used to establish the unit rates. Additionally, each rate includes a determination of optimum crew sizes for each task.

Traditional methods of making sun-dried adobes are essentially unchanged for countless generations in many parts of the world. The adobes at Chan

Chan are not kiln hardened nor are they stabilized with binders such as straw, making them inherently unstable and only marginally stronger than the original soil.

The adobe-making process involves combining a sandy clay soil and water in a shallow mud pit, then mixing with a shovel or hoe, or by foot treading. Wooden forms capable of making single or multiple bricks are set on level ground and the interior of the form is moistened with water. The adobe maker (*adobiero*) drops or throws the mixture into the form(s), kneads it to fill the corners and remove air bubbles, then levels the top with a stick or board. The forms are removed immediately, rinsed, and prepared for the next charge of mud. In low humidity climates such as Chan Chan the initial drying time is two to three days (McHenry 1984, 63). After this initial period, the bricks are tipped on edge, trimmed and continue to cure an additional few days. While the full curing process occurs in ten to 20 days, adobes may be transported and installed after five to seven days (Quentin Wilson, verbal communication with author, 2000).[1]

Productivity rates for making adobes vary by source in the composition of crews and tools used. Table 11.2 represents a format that brings each estimate to a common unit of measure, allowing for adjustments as needed. The raw data of the first two sources state that two workers with a wheelbarrow, hose, and a four-unit form make between 350 and 500 (35 cm × 10 cm × 25 cm) bricks per eight-hour day. An informant working in the Moche Valley, when questioned during this field research, indicated that he mixes and makes 300 bricks in three days, with a single brick form, carrying his own water about 50 m. The estimated unit rates reflect extending and converting the adobes made per day into hours per cubic meter of bricks produced. The rates range from 3.5 to 8 hr/m^3.

However, the makers of adobes at Chan Chan did not have a wheelbarrow nor as convenient a source of water as a hose, evident in the first two estimates. Conversely, they must certainly have used at least a four-unit form, unlike the informant, due to the mass production requirements of the project. To more closely replicate the techniques used by the Chimu, each of the estimates needs refinement. One person added to the first two crews allows for manual transportation of material and the informant's production raised by 20% to reflect the increased productivity of using four-unit forms. These adjustments are subjective and depend on construction experience and confidence in the initial data. The resulting recap indicates the range of productivity expected to manufacture adobes in terms of *optimistic*, *most likely*, *and pessimistic* unit rates. The informant's productivity is accepted as the *most likely* rate since it is more conservative than the average and most closely represents the actual methods used by the Chimu. The data indicate that each worker produces approximately 29 average sized adobes per hour, with an optimum crew size of three to five workers. In terms of productivity, the *most likely* unit rate for each worker is 7 hr/m^3.

Table 11.2 Productivity rates for manufacturing adobes

Rates for adobe production based upon hand-carrying materials and a four-unit form.
Average adobes at Rivero: 24 cm × 11 cm × 19 cm (approx. volume = 0.005 m^3)
Adobes in survey: approx. 35 cm × 10 cm × 25 cm (approx. volume = 0.009 m^3)

Source	No. of workers	Hours worked	Total hours	No. of adobes made	Volume of adobes nade	Unit rate
RAW DATA						
Wilson	2	8	16	500	4.59 m^3	3.49 hrs/m^3
McHenry	2	8	16	350	3.21 m^3	4.98 hrs/m^3
Informant	1	24	24	300	3.00 m^3	8.00 hrs/m^3
ADJUSTED RATES						
Wilson	3 [1]	8	24	500	4.59 m^3	5.20 hrs/m^3
McHenry	3 [1]	8	24	350	3.21 m^3	7.50 hrs/m^3
Informant	1	24	24	345 [2]	3.45 m^3	7.00 hrs/m^3
Recap: manufacture adobes						**No. of average size adobes made per hour**
Crew size		**3–5 adobieros**				
Productivity range				%		
Optimistic	5.2	person-hours/m^3 per worker		-25%		38
Most likely	7.0	person-hours/m^3 per worker		0%		29
Pessimistic	7.5	person-hours/m^3 per worker		7%		27
(McHenry 1984, 7)						

[1] Raw data based upon two persons with a wheelbarrow, hose, and a four-unit form. Add one extra person for manual transportation of mud and water.
[2] Raw data based upon one person with no wheelbarrow and a one-unit form. Increase output by 20% to compensate for one-unit form.

(Quentin Wilson verbal communication with author, 2000)

Manual transportation of material is a function of weight and distance. Mud bricks, the size of average adobes at Rivero, weigh approximately 7.5 kg each (McHenry 1984, 65; Norton 2001, 38), with a load of 4 adobes weighing 30 kg. For the purposes of this example, assume the adobe making area is 250 m from the site of the storeroom. Table 11.3 delineates the productivity rates derived from experimental sources for a 250-m hauling distance.

Erasmus' research at Uxmal (1965) involved performing various manual transportation experiments using workers in Sonora, Mexico to simulate Maya labor productivity. Rock-carrying experiments yielded productivity rates for manually transporting weights over distances with the raw data using a five-hour workday due to the strenuousness of the task and oppressive tropical climate. According to these data, a worker can transport a total of 950 kg over a 250-m route in a five-hour day, carrying a weight of 28 kg per trip. While the work is no less strenuous at Chan Chan, the climate is more hospitable and terrain less hazardous. Erasmus' rates are refined to allow an increased total for an eight-hour workday, tempered for a productivity drop in the later hours. The revised productivity rate using this data is approximately 9 hrs/m^3 for a 250-m trip.

A second method for estimating productivity uses a standard formula derived from United Nations' experiments as presented by Abrams (1994, 44) in his study of energetics of Maya structures. The formula accounts for weight of the load, speed of the worker loaded and unloaded, and the distance carried. The results of the calculation yield unit rates of 6.7 hrs/m^3 for a 250-m trip.

Since both sources of data are reasonably consistent in terms of productivity, the *most likely* rate equates to a simple average of the two. Carrying materials is a singular task so the crew size is simply measured as one person.

Construction of adobe walls uses simple, time-tested techniques that emphasize quantity over quality, strength over skill. The curing rate of the adobes and the mortar are the primary limiting factors to the speed of raising a wall. Moisture from uncured adobes and/or mortar must migrate to the surface to evaporate, otherwise a compression failure occurs and the wall collapses. In the arid climate of the north coast of Peru adobes achieve a full cure in ten to 20 days, though placement may occur within a week of manufacture with final curing taking place in the wall, providing the coursing is not too rapid (Quentin Wilson, verbal communication with author, 2000).[1] Similarly, too many courses placed upon uncured mortar may also cause compression failure and collapse of the wall. A rate of two to three courses per day of the relatively tall adobes at Chan Chan is adequate to allow the moisture in the core to evaporate.

To build the walls of the storeroom, string lines mark the perimeter, and the corners are built up first. Workers then infill the sections between the corners in courses following the string lines. On thick walls, workers simply

Table 11.3 Productivity rates for transporting adobes

Adobe bricks weight approximately 1500 kg/m^3
An average adobe weighs approx. 7.5 kg, with a volume of 0.005 m^3
A load of four adobes weighs 30 kg, with a volume of 0.02 m^3

Erasmus

One worker can carry 950 kg/day over a distance of 250 m in a five hour day
Adjusted for an eight hour day =

950 kg/day/5 hrs/day = 190 kg/hr
190 kg/hr × 8 hrs/day = 1520 kg/day
1520 kg/day × 85% efficiency = 1292 kg/8 hrs. = .006 hrs/kg
Equivalent hourly rate: .006 hrs/kg × 1500 kg/m^3 = **9.0 hrs/m^3**

Abrams

$$m^3/hr = Q \times \frac{1}{(L/V + L/V^1)}$$

$$0.02 \times \frac{1}{((0.25/3) + (0.25/5))}$$

$$0.02 \times (1/0.13333) = 0.15\ m^3/hr$$

Equivalent hourly rate: **6.7 hrs/m^3**

Where:

Q = Quantity per load (30 kg)	0.02 m^3
L = Distance	0.25 km
V = Velocity loaded	3 km/hr
V^1 = Velocity unloaded	5 km/hr

Recap: transport adobes – 250 m

Crew size	**1**	**Laborer**	
Productivity Range			
Optimistic	6.7	person-hours/m^3 per worker	–15%
Most likely	7.8	person-hours/m^3 per worker	0%
Pessimistic	9.0	person-hours/m^3 per worker	15%

(Erasmus 1965, 387) (Abrams 1994, 44)

stand on the previous courses and work backwards placing the bricks and mortar as they go. Workers pass the bricks and mortar up to the mason with minimal or no scaffolding on walls up to three m in height.

Since adobe construction remains essentially unchanged from the time of the Chimu, contemporary sources provide a good starting point. One published standard estimates placement of 555 adobes (35 cm × 10 cm × 25 cm) by a five-person crew, in eight hours, while Wilson (verbal communication with author, 2000)[1] recorded a rate of 500 bricks with a three-person crew (Table 11.4). To accommodate varying brick sizes, the numbers of bricks are converted into their equivalent volumes. This yields a reasonably accurate measurement of productivity across the range of brick sizes. However, each assumes the use of a wheelbarrow, a convenient water source, and a machine mixer for mortar. Since the Chimu employed only manual methods, the addition of two workers to each crew adjusts the rates to consider manual transportation and mixing of materials. The resulting data from both sources are relatively consistent and form the upper and lower limit of the productivity range. The *most likely* rate of 10 hrs/m^3 of wall is the average, with an optimum crew of four to six workers.

Project estimate

Table 11.5 is the result of combining the installed quantities with the *most likely* unit rates, on a per-activity basis according to the WBS. An analysis of the data reveals the total estimate for the storeroom is 1,184 person-hours. Construction of the adobe shell is by far the most expensive component, with manufacturing, transporting, and installation of adobes representing much of the labor. The roof is a relatively minor portion of the project. The distance material is transported to the site has a sizeable impact on the overall cost. Transportation costs of adobe and *cana* alone represent more than 30% of the total project cost. Based upon this information, a contractor would attempt to keep the hauling distance to a minimum, and concentrate management attention to the adobe-related activities.

Regarding the overall confidence level of the estimate, there is solid productivity data for the adobe manufacturing, transporting, and installation, the primary consumers of labor. Since data were not available to estimate accurately the fabrication and erection of the roof panels, there is the temptation to perform an experiment to establish accurate rates. However, it is likely that these activities have a slight impact on the project. Unless the unit rates are under- or overestimated by a vast margin, data gained from a field experiment would do little to improve the overall accuracy of the estimate. The same situation exists with hand plastering for similar reasons. This estimate review is ideally suited as a means of determining the impact of weak or missing data as well as determining the direction of future research designs.

Table 11.4 Productivity rates for installing adobes

Source	*No. of workers*	*Hours worked*	*Total hours*	*No. of adobes installed*	*Volume of adobes installed*	*Unit rate*
RAW DATA						
Wilson	3	8	24	500	4.59 m^3	5.23 hrs/m^3
Means	5	8	40	555	5.09 m^3	7.85 hrs/m^3
ADJUSTED RATES						
Wilson	5[1]	8	40	500	4.59 m^3	8.72 hrs/m^3
Means	7[1]	8	56	555	5.09 m^3	11.00 hrs/m^3

Recap: adobe installation				**No. of average size adobes installed per hour**
Crew size		**4 – 6 masons**		
Productivity range			%	
Optimistic	8.7	person-hours/m^3 per worker	–12%	23
Most likely	9.9	person-hours/m^3 per worker	0%	20
Pessimistic	11.0	person-hours/m^3 per worker	12%	18

(R.S. Means 1999, 134)

[1] Raw data based upon a wheelbarrow, hose, machine mixer for mortar.
Add two extra persons for manual mortar mixing and transportation of mud and water.
(Quentin Wilson verbal communication with author, 2000)

Construction planning and scheduling

The project schedule represents the construction work plan showing how the activities relate to one another in the construction sequence, and using the length of time required for each activity, calculates the total length of the project.

Logic diagrams

A logic diagram, or network, is a graphical method used to define how each activity relates to every other activity, and is the basis for the project schedule. Each of the activities represents a separate yet interdependent task. Development of the logic diagram proceeds systematically on an activity by activity basis to sequence the work. In the precedence diagramming method (PDM), boxes represent activities and arrows represent the logical relationships. Each activity is analyzed in terms of which activities must be completed before it can begin (predecessors), and which activities must wait until it is completed (successors). Figure 11.4 is a simple logic diagram for the storeroom and is a graphical representation of the construction work plan that reflects the results of many decisions and chosen alternatives. This example shows that once the project starts, fabrication of the roof panels (including procurement of the raw materials) and manufacturing of the adobes can both begin and occur concurrently. Erection of the adobe walls (successor) cannot start until enough adobes have been manufactured and delivered to the site so as not to slow down the installation process (predecessors). While it is technically possible to erect the roof panels before the walls and floor are plastered, this work plan allows the adobe workers to complete the shell of the storeroom, including the wall and floor plastering, before the roof installation begins. This allows the adobe workers to complete their portion of the project without having to work around the

Table 11.5 Labor estimate of storeroom

Item description	*Estimated quantity*		*Unit rates*		*Total person hours*
ADOBE SHELL					
Manufacture adobes	40.19	m^3	7.00	hrs/m^3	281
Transport adobes	40.19	m^3	7.80	hrs/m^3	313
Erect adobe wall	40.19	m^3	9.90	hrs/m^3	398
Plaster walls and floor	68.70	m^3	0.83	hrs/m^3	57
Subtotal – labor estimate of adobe shell					1,049
ROOF					
Procure & fabricate roof panels	4	ea.	29.80	hrs ea.	119
Install roof panels	4	ea.	4.00	hrs ea.	16
Subtotal – labor estimate of roof					135
Total person-hours for storeroom					**1,184**

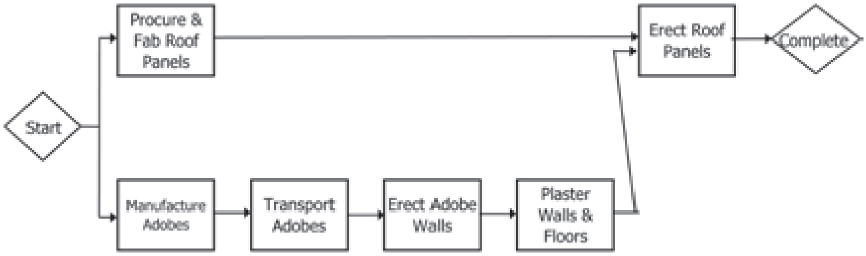

Figure 11.4 Logic diagram for storeroom

roofing installation, resulting in a smoother work operation. The judicious and creative use of logic allows the builder to accurately model work plans and compare the effects of various alternatives.

Activity durations

The length of time required to complete an activity, the duration, is a function of the estimated person-hours, crew sizes, and the length of the workday. It is determined by dividing the total number of workers, times the hours in a workday, into the total person-hours. The object is to balance the crew assignments within a desired timeframe to meet the goals of the project. The labor/crew requirements and the activity durations are shown in Table 11.6.

Resource distribution

Next, the schedule is resource loaded to determine the resource requirements or labor distribution of the project. Figure 11.5 shows the results of combining the logic developed in Figure 11.4, and the duration data in Table 11.6, as a resource loaded, time-scaled logic diagram presented in bar chart form. Here each bar represents an activity's duration as well as its relationship to the other activities. The manufacture, transport, erection, and plastering of the adobes all proceed sequentially with the fabrication of the roof panels occurring concurrently. According to the logic, these activities must be complete before the final activity (Erect Roof Panels) can begin. The critical path for the storeroom consists of the activities Manufacture Adobes, Transport Adobes, Erect Adobe Walls, Plaster Adobe Walls and Floors, and Erect Roof Panels. They make up the longest path through the network, have no float, and represent the earliest time the project can finish, which is 35 days. A delay in any of these activities results in a delay to the project end date. The awareness and management of the activities on the critical path is vital to the on-time completion of the project. The activity Fabricate Roof Panels is eight days in duration with 26 days of float. That is,

Table 11.6 Crew sizes and durations

Item description		*Estimated quantity*		*Unit rates*		*Total person hours*	*Crew size*	*No. of crews*	*Total workers*	*Activity duration (days)**
		A	*x*	*B*	=	*C*	*D*	*x E*	*= F*	*G=C/(F*8)*
ADOBE SHELL										
	Manufacture adobes	40.19	m^3	7.0	hrs./m^3	281	4	1	4	9
	Transport adobes	40.19	m^3	7.8	hrs./m^3	313	1	4	4	10
	Erect adobe walls	40.19	m^3	9.9	hrs./m^3	398	4	1	4	13
	Plaster walls & floor	68.70	m^2	0.83	hrs./m^2	57	2	2	4	2
	Subtotal – labor estimate of adobe shell					1049				
ROOF										
	Fabricate roof panels	4	ea.	29.8	hrs./ea.	119	2	1	2	8
	Erect roof panels	4	ea.	4.0	hrs./ea.	16	2	1	2	1
	Subtotal – labor estimate of roof					135				
Total person-hours for storeroom						**1184**	*1 day = 8 hrs. rounded UP to whole day.			

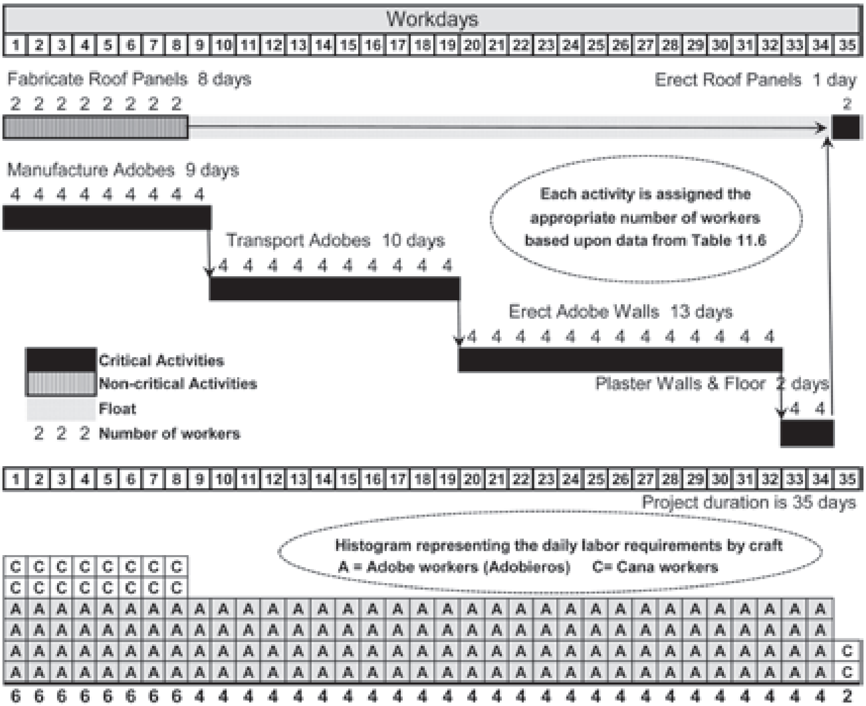

Figure 11.5 Resource-loaded bar chart

this activity may begin as early as day one of the project or as late as day 27 without delaying the start of the Erect Roof Panels activity. In effect, this eight-day activity can happen anytime in a span of 34 days. In this example, the resources are assigned by type of workers. It shows a range of two to six workers needed to build the project according to the early schedule. Four adobe workers work from day 1 to day 34 of the project, with the two *cana* workers required at the beginning and the end.

The schedules developed in this section are the result of basic scheduling and resource allocation techniques. In addition to the straightforward use of CPM for this case study, virtually all CPM programs have extensive capabilities to manage time and resources to more accurately model project plans. For example, in this study, the work schedule was assumed to be eight hours per day, five days per week. Whether or not this is correct is unknowable but works well as a baseline for comparison to other scenarios. CPM is especially useful in cases where a researcher wishes to model and compare the effects of alternate scenarios based upon ethnographic evidence. For example, it might be posited that the labor force instead worked a 12-hour workday six days per week with three months off during the planting and harvesting seasons. CPM software can analyze and compare the results of

both scenarios and access the impact of the differences. Similarly, the availability or lack of certain resources can also be modeled with regards to quantities and time. Perhaps it is determined that cana crops must be harvested only during the summer months, or that a resource such as water or labor is in limited supply during some of all of the project duration. The capability of handling these types of multiple variables to conduct "what-if" analysis is the major contributor to its universal use in managing construction projects, and similarly makes it a powerful analytical tool for evaluating differing theories of labor and resource utilization in an archaeological context. Advanced scheduling techniques including the management of limited resources and developing complex logic are more fully developed in earlier papers (Smailes 2000, 2011).

Probabilistic scheduling

The estimated project duration is 25 days with an unlimited labor supply, or 39 days with a group of four workers. However, CPM scheduling is deterministic and uses a single estimate and duration derived from the *most likely* unit rates. By presuming there is no uncertainty in productivity, there is no accounting for variability. Nevertheless, uncertainty in productivity does exist since it is impossible to make precise correlations when estimating prehistoric construction. This uncertainty is represented by the optimistic, pessimistic, and most likely range of unit rates calculated for each activity, and the effect of this uncertainty on the project's estimate and schedule is quantifiable in terms of probabilities.

Program evaluation and review technique (PERT) takes statistical sampling programs such as Monte Carlo[2] combined with CPM schedules to simulate numerous project outcomes based upon the full range of productivity rates. Table 11.7 shows the project estimate expanded to include the full range of unit rates previously developed. These rates then translate to the estimated person-hours and durations by activity. For instance, the deterministic values for manufacturing adobes, which were the basis for the CPM schedules, are 280 person-hours over a nine-day duration. However, this activity could optimistically take as few as 210 person-hours over a seven-day duration, or as many as 300 person-hours over a ten-day duration.

To determine the probable project cost and durations, the full range of values is factored into the schedule, then simulated using Monte Carlo sampling for 1,000 cycles. Each simulation cycle randomly samples durations across a triangular distribution defined by the *optimistic*, *most likely*, and *pessimistic* durations for each activity. Frequency distribution histograms and cumulative probability curves plot the results.

Figure 11.6 shows there is a 69% probability of completing the project in 1,184 person-hours, the deterministic value, but a 95% probability the project will require 1,230 person-hours or less. In terms of the overall project

Table 11.7 Crew sizes and durations – PERT version

Item description	*Estimated quantity*		*Unit rates*		*Total person hours*	*Crew size*	*No. of crews*	*Total no. of workers*	*Activity durations (days)**		
									Optimistic	*Most likely*	*Pessimistic*
	A	*X*	*B*	=	*C*	*D*	*x E*	*= F*	*G=C/(F*8)*	*G=C/(F*8)*	*G=C/(F*8)*
ADOBE SHELL											
			5.2	hrs./m^3	210			4	7		
Manufacture adobes	40.2	m^3	7.0	hrs./m^3	280	4	1	4		9	
			7.5	hrs./m^3	300			4			10
			6.7	hrs./m^3	268			4	9		
Transport adobes	40.2	m^3	7.8	hrs./m^3	315	1	4	4		10	
			9.0	hrs./m^3	363			4			12
			8.7	hrs./m^3	350			4	11		
Erect adobe walls	40.2	m^3	9.9	hrs./m^3	396	4	1	4		13	
			11.0	hrs./m^3	442			4			14
			0.57	hrs./m^2	39			4	2		
Plaster walls & floor	68.7	m^2	0.83	hrs./m^2	57	2	2	4		2	
			0.98	hrs./m^2	67			4			3
ROOF											
			23.9	hrs./ea.	95			4	3		
Fabricate roof panels	4	ea.	29.8	hrs./ea.	119	2	2	4		4	
			36.5	hrs./ea.	146			4			5
			3.2	hrs./ea.	13			2	1		
Erect roof panels	4	ea.	4.0	hrs./ea.	16	2	1	2		1	
			4.8	hrs./ea.	19			2			2
			Optimistic		976	person-hours					
		Estimate totals:	Most likely		1,184	person-hours			*1 day = 8 hrs. rounded UP to whole day.		
			Pessimistic		1,337	person-hours					

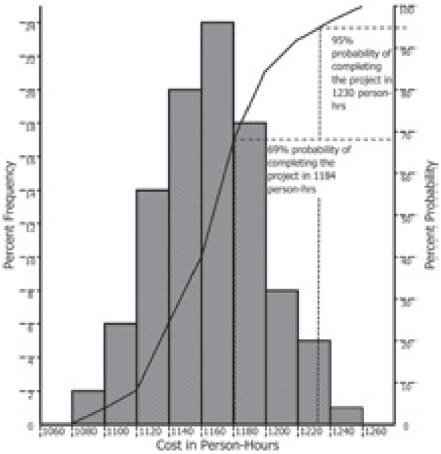

Figure 11.6 Estimated cost probability graph

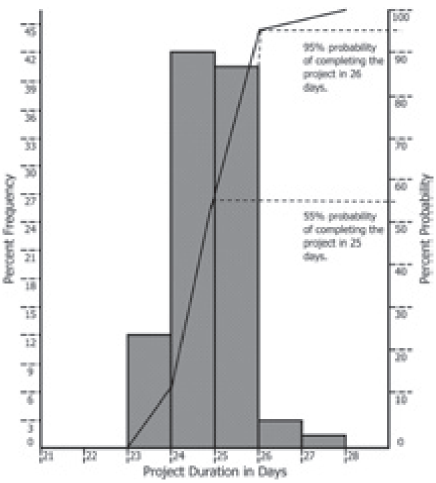

Figure 11.7 Schedule probability graph

length, the simulated project durations range from 24 to 28 days, with a 95% probability that the project will finish in 26 days (see Figure 11.7).

Construction of Ciudadela Rivero

General description of major features

The ciudadelas of Chan Chan represent the architectural expression of the apex of power (see Figure 11.1). Massive adobe walls rising to nine m high

and as much as half a km in length surround them. They served as the administrative center of the kingdom, the royal palaces of the kings and their immediate families, and with the addition of a burial platform, a mausoleum upon their death (Day 1973, 281). Generally, the ciudadelas are divided into a north, central, and southern sector called the *conchone* that contains a burial mound (see Figures 11.8 and 11.9). The north and central sectors each contain numerous plazas, storage buildings, and U-shaped structures called *audiencias*. Using massive walls, restricted access, and changes in elevation, this purposeful design isolates the elite from commoners, and represents a formal planning tradition that endured for hundreds of years. Ciudadela Rivero was best suited for analysis from a construction perspective due to its extensive mapping and existing research.

The compound making up the existing configuration of Ciudadela Rivero measures approximately 185 m wide by 380 m long surrounded by massive walls up to 9 m high tapering from 4 m at the base to 1 m at the top. On the north, east, and west sides, an outer adobe wall and inner *tapia* (rammed earth) wall run parallel separated by a 3- to 4-m wide corridor. On the south end, the exterior adobe walls turn the corner and abut the *tapia* wall. On the north end, the inner *tapia* wall ends abruptly leaving a 95-m gap.

The interpretation of the architecture at Chan Chan contributes significantly to theories of the social, political, and economic structure of the Chimu. The monumental size of the ciudadelas implies the control of labor, the spatial layout suggests differences in rank, and the large proportion

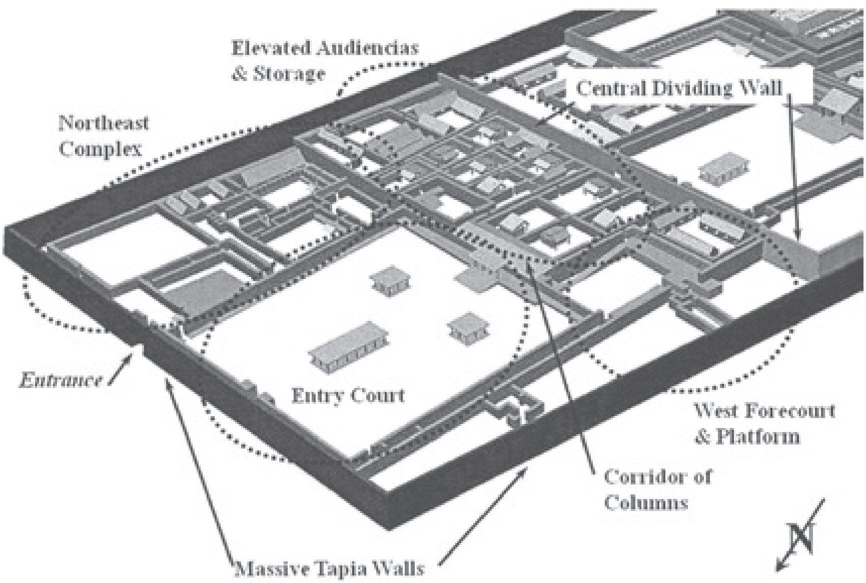

Figure 11.8 Layout of north and center sector of Ciudadela Rivero

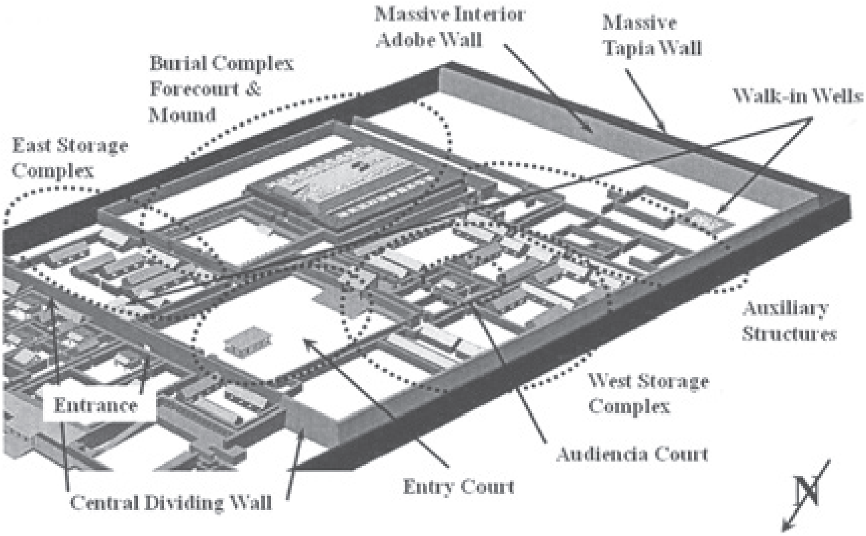

Figure 11.9 Layout of south and center sector of Ciudadela Rivero

of space allocated to storage infers centralized control of a redistributive economy. However, there are no reliable estimates of how much labor was involved in constructing a ciudadela, how long it may have taken to build, and what degree of control and coordination was required. These data are directly relevant to theories concerning the sociopolitical organization of the Chimu.

Scope of work

The existing layout of Ciudadela Rivero is the result of at least two major construction episodes. The abutments of the adobe walls into the tapia walls, the lack of any transition of the shortened north tapia walls into the final structure, and the fact that no other ciudadela had twin perimeter walls strongly suggests that originally, only a single tapia wall surrounded the ciudadela. The existing layout is the result of a later remodeling effort involving the demolition of a portion of the north tapia wall, a rework of the north entry corridor, and the addition of the massive adobe outer wall. Only the analysis for the original configuration is addressed here. It is possible and even probable that remodeling occurred in other areas of the compound, however, there is no compelling data that allows any further demarcation between original and remodeled areas. Also, specifically excluded are any instances of artwork, primarily the plaster reliefs on the walls of the courtyards. Although artistic work is often difficult to quantify in terms of person-hours, it is doubtful that the time or effort expended is

significant in terms of the overall construction estimate. Further, it is highly unlikely that this work would be on the critical path and therefore would have no impact on the overall duration of the project.

Labor quantification

Quantity survey. Aided by plan maps (Mackey and Moseley 1974) and a detailed architectural survey of the compound (Day 1973), field research was conducted at Chan Chan in May 2000 to photograph, measure, and analyze the ruins of Ciudadela Rivero from a construction perspective. Data from these sources were used to create a three-dimensional virtual model of Ciudadela Rivero (see Figures 11.1, 11.8, 11.9).

This architecturally intelligent model associates sizes, material types, and quantities for each detailed component of the compound. While it is possible to perform the quantity survey manually, the model allowed the installed quantities of each component to be extracted directly from the model and input into the quantity survey according to the WBS.

Productivity – unit rates. Proceeding in the same manner as previously shown, unit rates were developed for all the tasks required to construct the compound. Unit rates previously calculated for adobe wall construction are not sufficient to account for walls over three m high and require adjustment. As with the construction of tapia walls, a loss of productivity occurs as the height increases, primarily due to the additional transportation of the adobes. For heights between three and six m, the equivalent of two additional workers to the crew size reflects this decreased productivity, with four additional workers being added for heights between six and nine m. Table 11.8 lists the full range of tasks, unit rates, and crew sizes.

Project estimate. Based upon the *most likely* productivity rates, the project estimate for the construction of Ciudadela Rivero in its original configuration is 2.1 million person-hours (Table 11.9). Building the interior walls and structures in the north sector, central sector, and conchone accounts for half of the labor. Constructing the massive outer tapia and inner adobe walls consumes one-third. The balance is in general excavation.

The distribution of person-hours from a work type perspective indicates that manufacturing, transporting, and installing adobes represents two-thirds of all work. The tapia walls and excavation account for just under a third, with the balance in plastering and *cana* related activities.

In terms of the uncertainty of the estimate, each unit rate developed consisted of a productivity range represented by *optimistic*, *most likely*, and *pessimistic* values. Using this range of rates, the uncertainty in productivity is quantified by the Monte Carlo simulation procedure described previously. The results (see Figure 11.10) show there is an 85% probability of completing the project in 2,123,784 person-hours, the deterministic estimate, with a 95% probability the project could have been completed in 2,136,000 person-hours or less.

Table 11.8 Recap of productivity rates for Ciudadela Rivero

Item description (Activity)	*Unit of measure (UOM)*	*Person-hours per UOM*			*Crew size*
		O	*ML*	*P*	
Hand excavation	m^3	4.90	6.00	7.30	1
Excavate walk-in wells	m^3	4.90	6.00	7.30	1
Manufacture adobes	m^3	5.20	7.00	7.50	5
Transport adobes	m^3	6.70	7.80	9.00	1
Erect adobe structures	m^3	8.70	9.90	11.00	5
Erect adobes wall 0 – 3 m high	m^3	8.70	9.90	11.00	5
Erect adobes wall 3 – 6 m high	m^3	12.20	13.80	15.40	5
Erect adobes wall 6 – 9 m high	m^3	15.70	17.70	19.80	5
Erect tapia walls 0 – 3 m high	m^3	8.50	10.70	12.80	5
Erect tapia walls >3 – 6 m high	m^3	11.90	14.90	17.90	5
Erect tapia walls >6 – 9 m high	m^3	15.40	19.20	23.00	5
Plaster walls 0 – 3 m high	m^2	0.57	0.83	0.98	2
Plaster walls >3 – 6 m high	m^2	0.86	1.25	1.47	2
Plaster walls >6 – 9 m high	m^2	1.15	1.66	1.96	2
Harvest algorrobo	m	2.60	3.25	3.90	4
Fabricate roof panels	each	23.90	29.80	36.50	2
Erect roof panels	each	3.20	4.00	4.80	2

O = Optimistic ML = Most likely P = Pessimistic

Table 11.9 Distribution of person-hours by area and work type

By area	*Estimated person-hours*	*Percent of total*
Sitework – general excavation	259,296	12.2%
Massive tapia walls	369,152	17.4%
Massive adobe walls	319,184	15.0%
North sector	383,544	18.1%
Central sector	786,552	37.0%
Conchone	6,056	0.3%
Total	2,123,784	100%
By work type	*Estimated person-hours*	*Percent of total*
Excavation	259,290	12.2%
Manufacturing adobes	551,972	26.0%
Transporting adobes	481,002	22.6%
Installing adobes	340,944	16.1%
Plastering	93,609	4.4%
Tapia work	379,907	17.9%
Cana/roofing	17,060	0.8%
Total	2,123,784	100%

Scheduling

A project schedule is the representation of a specific construction work plan concerning the sequencing of work and the deployment of resources. It is technically possible to stretch the construction of the ciudadela over decades

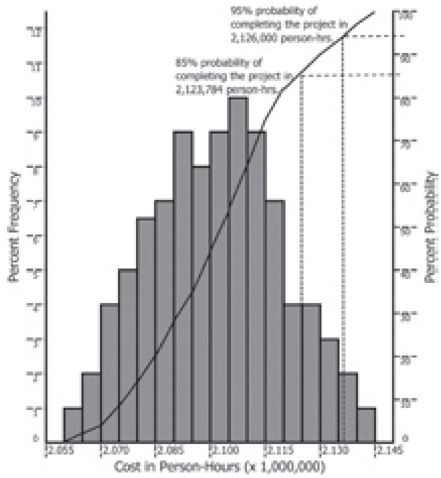

Figure 11.10 Estimated cost probability graph for Ciudadela Rivero

using a small number of workers, or to work in seasonal or intermittent spurts. Similarly, intensifying the effort by using more workers than the optimum can reduce the construction time, although a loss of overall productivity is likely. Each case introduces any number of specific assumptions, and while it is possible to simulate these options, the purpose here is not to test every possibility, but to demonstrate the methodology and establish baselines of how long the project *could have* or *should have* taken under *normal* circumstances. This baseline approach assumes each construction episode worked continuously in a relatively diligent and efficient manner.

The development of a construction work plan, building strategies, and labor organization are discussed in detail in earlier publications (Smailes 2000, 2011).

Optimum schedule. The schedule representing the quickest practical completion of the ciudadela assumes unlimited labor available on an as-needed basis. Based on the *most likely* durations, and a 5-day, 40-hour workweek, the estimated completion time is 61 calendar months. However, this schedule necessitated peak labor utilization ranging from between 200 and 400 workers and the requirement to call upon and release large numbers of workers on a short-term basis makes this schedule theoretically possible, but not necessarily practical. By limiting the overall number of workers and smoothing the major peaks in labor, the estimated completion time is 67 calendar months (see Figure 11.11) with an average peak labor requirement of 250 workers.

Probabilistic testing. Using the full range of *optimistic*, *pessimistic*, and *most likely* durations, the schedule indicated only a 30% probability of finishing within the deterministically derived end date of 67 months. The schedule indicated a 95% probability of finishing in 70 months (see Figure 11.12).

Work Area	Person Hours
Sitework	259,296
Massive Tapia Walls	369,152
North Sector	383,544
Massive Adobe Walls	319,184
Central Sector	786,552
Conchone	6,056
Total Original Configuration	2,123,784

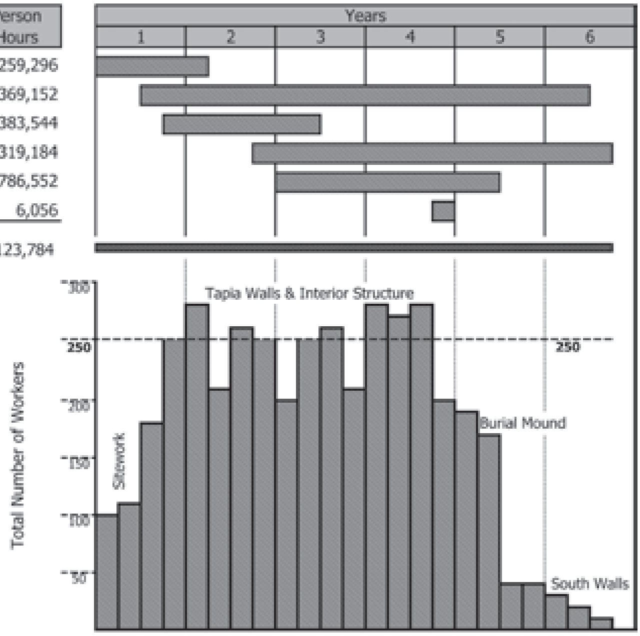

Figure 11.11 Optimized schedule for Ciudadela Rivero

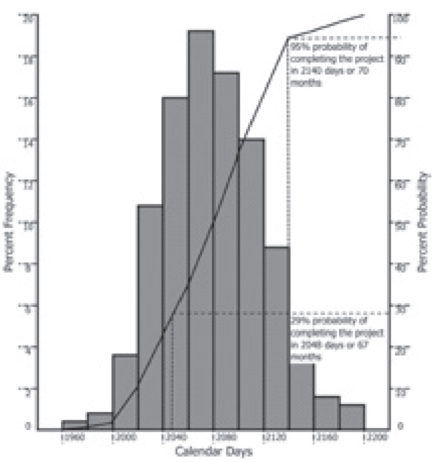

Figure 11.12 Schedule probability graph for Ciudadela Rivero

Conclusions

The total labor investment in the original configuration of Ciudadela Rivero is roughly 2.1 million person-hours. A workforce of roughly 250 persons, working continuously could have constructed Ciudadela Rivero in 67 months, based

on a five-day, 40-hour workweek. These estimates and schedules represent practical and achievable objectives under normal circumstances and are the baseline for comparisons to other structures and labor organization strategies.

While substantial in size and scale, the labor requirement of 250 workers to construct Ciudadela Rivero is quite modest, especially since an estimated 30,000 persons inhabited Chan Chan during its final phase (Topic and Moseley 1983, 157). Even doubling the average labor force to an average of 500 workers to crush the schedule to its shortest possible duration represents a relatively minor part of the population dedicated to construction.

There does not appear to be the need to import workers from surrounding areas (Mackey 1987, 127; Mackey and Klymyshyn 1981, 104), since redirecting a small portion of the resident population to constructing a single ciudadela seems entirely feasible. Even the most aggressive building program represented by the simultaneous construction of the last four compounds does not have enough impact to cause any major shifts in the local economy.

Due to the manageable size of the workforce, it is possible that the residents of Chan Chan bore the tax levied to construct the ciudadelas while the rural population met their obligations at or near their own region. Rotating groups from within the resident population gives considerably more control and flexibility to the builders than coordinating, feeding, and housing workers from a distant community. In addition, relying upon the non-agricultural resident workers has the advantage of eliminating the seasonal availability of workers. If workers living outside of Chan Chan performed the construction, the decision to use outside labor rather than the resident population was one of choice not necessity.

One of the foundations of ancient Andean societies, the ability to mobilize large workforces to construct monumental architecture, had its beginnings on the northern coast of Peru (Moseley 1975b, 40; Schwartz 1982, x). While more labor-intensive efforts are evident in structures such as the Pyramids of the Sun and Moon in the Moche Valley, it is difficult to extend the concept of controlling massive workforces to the construction of the ciudadelas at Chan Chan. Considering this research, theories concerning the control of mass labor and social complexity based solely on the monumental architecture of Chan Chan need revisiting.

Acknowledgments

Few things in life are created by individuals working solo, so recognition of the numerous people who shared their time and wisdom to assist me with this work is warranted. Brisbane H. Brown, Jr. was both my mentor and friend for almost 40 years. Dr. Brown was responsible more than anyone else for my development as a student, teacher, and researcher. He thought my idea of a construction management professional contributing to the field of archaeology was commendable and he was behind me 100%, provided I could find an archaeologist to confirm that the research was consequential.

Michael E. Moseley was that archaeologist. As one of the premier researchers in ancient Andean culture, Dr. Moseley not only welcomed my research but shared his insights, posed questions, generously shared his contacts, and made sure that I had a good grounding in archaeology as I pressed on.

My thanks to Quentin Wilson, the director emeritus of Northern New Mexico College's Adobe Construction Program. He unselfishly taught me everything I know about adobe construction, which is only a fraction of what he knows. At the time of my initial research Ana Maria Hoyle Montalva was the director of the National Institute of Culture La Libertad in Trujillo, Peru. She graciously allowed me complete access to the World Heritage site of Chan Chan for my research. Marla Holden, my TA, friend, and colleague did most of the editing. Numerous persons involved in archaeology and operations research gave me advice and guidance along the way including but not limited to Ian Flood, Carol Mackey, Jerry Moore, Elliot Abrams, Peter Bleed, Susan Niles, and Brian Bauer. An anonymous reviewer provided useful comments on a previous draft of this chapter. Finally, thank you to my wife Becki, who has read, corrected, reread, critiqued, and re-reread so much of my research to the point that she knows as much about the topic as me. I can never repay her support through the years, but I am trying.

Notes

1 Quentin Wilson, instructor of adobe construction, Northern New Mexico Community College.

2 Monte Carlo 3.0k for Primavera. Copyright 1996, Primavera Systems, Inc. Under license to the M.E. Rinker Sr. School of Construction Management, University of Florida.

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12 Towards a multiscalar comparative approach to power relations

Political dimensions of urban construction at Teotihuacan and Copan

Tatsuya Murakami

Introduction

Power relations are multifaceted with a multiplicity of bases (Mann 1986; McGuire 1983; Paynter and McGuire 1991; Sewell 1992). Different individuals and collectivities continuously negotiate their power and identity at multiple scales of social interaction, which results in social reproduction and transformation. Architecture represents both the medium and the consequences of such negotiation and, thus, provides a tangible means to elucidate some aspects of social negotiation. This chapter explores how we can expand the scope of architectural energetics through the comparison of Teotihuacan and Copan at multiple scales of social interaction.

Teotihuacan and Copan, contemporaneous state capitals in Classic period Mesoamerica, represent excellent cases for comparative study for various reasons. First, these two cities, or Teotihuacan and Classic Maya centers in general, have long been contrasted in terms of urban organization (Drennan 1988; Sanders and Webster 1988), state organization (e.g. city-states versus regional state; see Trigger 2004), and political strategies (Blanton et al. 1993; Blanton et al. 1996). Second, Teotihuacan and Copan represent two of a handful of cases in which architectural energetics has been applied to both monumental and residential structures as well as to elite and nonelite structures (Abrams 1987, 1994; Murakami 2010, 2015). While both the quality and quantity of energetic data are vastly different between these two cities due to distinctive research objectives, my study at Teotihuacan basically followed the procedure outlined by Abrams (1994) and the energetic data are comparable. Instead of synchronic comparison along a single dimension, this study compares diachronic changes in power relations at four different analytical scales: the absolute and relative power of the state, relations among state elites/institutions, state-subject relationships, and relations among subjects. Through these multiscalar comparisons between Teotihuacan and Copan, this study demonstrates similarities and differences in the trajectory of changing power relations embodied by architecture and discusses its implications for better understanding how differential manifestations of urban landscapes (e.g. low-density and high-density urbanism)

were entangled with political strategies and historically contingent processes of social transformation.

Analytical frameworks for multiscalar comparisons

One of the strengths of architectural energetics is that it facilitates the comparison of the social and material resources of those who commissioned the construction. The quantitative comparison then provides a basis for making inferences on qualitative differences of social relations. The unit of comparison may vary from a residence to a neighborhood to an institution to a whole polity. This study explores a multifaceted comparative approach: it examines multiple aspects of power relations within the respective city and then compares these aspects between two cities.

I use two different units of measurement: total labor costs in *person-days* and per capita labor costs in *days per person*. When applied to state buildings, I refer to these two measures as *the extent of state power* and *the degree of state power*, respectively (Murakami 2015; see also Drennan and Peterson 2012; McGuire 1983; Nelson 1995; Roscoe 1993). These two measures should be assessed separately because an increase in total labor costs may simply reflect population growth, not necessarily per capita labor costs (but see Carneiro 1967, 2000).

Four analytical scales I employ in this study are the extent and degree of state power, relations among ruling elites/state institutions, relations among subjects, and state-subject relationship. For the extent and degree of state power I include structures within the central precinct within the respective city: structures along the Street of the Dead at Teotihuacan (Murakami 2015) and the Main Group of Copan. The assessment of state power is carried out for five consecutive phases of more or less comparable duration during the Teotihuacan period, from the Tzacualli to Metepec phases (c. 1–650 CE) (see Murakami 2010, 2015), whereas at Copan data are available from the first two rulers (Carrelli 2004) and some structures built during the eighth century CE (Abrams 1987, 1994; Webster and Kirker 1995). As for the relations among state elites/institutions, I examine how labor forces were allocated to different architectural complexes within the central precinct to illuminate diachronic changes in power relations among dominant elites. Although the function of each architectural complex remains poorly understood, especially at Teotihuacan, I make distinctions between ceremonial structures that would have served the general public (major pyramids) and administrative and residential structures (or palaces at Copan) that would have served limited numbers of dominant elites within precinct areas.

Relations among subjects are assessed through the comparison of labor costs for elite and non-elite residences outside the central precinct. State-subject relationship is assessed based on the comparison of labor costs for state buildings and those for elite and non-elite residences outside the central precinct. The results are interpreted in terms of the degree to which

labor is concentrated in the central precinct. Additionally, I compare labor costs for residential structures within the central precinct with those of residential structures outside it. For the ease of comparison, I refer to elites residing outside the central precinct as sub-royal and/or intermediate elites.

Background and datasets: Teotihuacan and Copan

Teotihuacan

Teotihuacan was the capital of a regional state in central Mexico between c. 150/200 and 550/650 CE with over 100,000 urban residents in an area of c. 20 km^2 (see Figure 12.1). Its urbanization process started around 100 BCE and the Teotihuacan state was consolidated likely around 200 CE (during the Miccaotli phase) as seen in the construction of major pyramids (Murakami 2010, 2014, 2015, 2016a; cf. Cowgill 2000; Millon 1981). Urban renewal projects started around 250/300 CE (the Tlamimilolpa phase) and more than 2,000 apartment compounds were built for urban residents. These apartment compounds were rebuilt subsequently during the Xolalpan and Metepec phases (c. 350–650 CE). Rebuilding of major pyramids ceased

Figure 12.1 Location of architectural complexes at Teotihuacan mentioned in the text (redrawn and modified after René Millon 1973)

during the Late Xolalpan phase (c. 450–550 CE) and the Teotihuacan state collapsed during the Metepec phase (c. 550–650 CE).

The datasets for this study consist of twelve excavated architectural complexes (see Figure 12.1): discrete, and in most cases walled, architectural units, each of which comprises multiple smaller units often called apartments or courtyard units. Apartment compounds are typical architectural complexes at Teotihuacan, but the central precinct also consists of multiple discrete architectural complexes. In order to compare power differentials among different social segments, I chose a sample of architectural complexes from three broadly defined strata of socioeconomic status, including dominant elites, intermediate elites, and middle to lower status citizenry of the city. I assume that buildings along the Street of the Dead were commissioned by the governmental institutions and thus reflect the power of dominant elites. Some excavated apartment compounds with a large courtyard and mural paintings are interpreted to pertain to intermediate elites

Figure 12.2 Location of architectural groups at Copan mentioned in the text (redrawn with modification after Fash 2001, Figure 42)

(Manzanilla 2006) and the rest of the excavated compounds to pertain to middle to lower status commoners (Millon 1976). For per capita labor costs I use the population figures of the entire Teotihuacan Valley instead of the population within the city boundary: 120,000 people for the Miccaotli phase, 150,000 people for the Tlamimilolpa and Xolalpan phases, and 120,000 people for the Metepec phase (Murakami 2010, 153).

Copan

The Copan dynasty was established in 426 CE by K'inich Yax K'uk Mo' in western Honduras and sixteen successive rulers have been identified thus far (Andrews and Fash 2005; Bell, Canuto, and Sharer 2004; Fash 2001). The central precinct or the Main Group consists of a large plaza to the north and a huge acropolis to the south, the latter consisting of major pyramids and royal palaces. All the structures were rebuilt multiple times and the scale of rebuilding climaxed during the eighth century CE before the collapse (Fash 2001; Webster 2002). Within the Copan Valley (or Copan Pocket; c. 24 km^2), there are several large-scale architectural complexes, probably residential and civic-ceremonial complexes of sub-royal and intermediate elites to the east and west of the Main Group (e.g. Group 9N-8), which are connected to the Main Group by causeways, and non-elite populations were dispersed within the valley and at the foothills to the north of the Main Group (see Figure 12.2).

While several building and rebuilding episodes have been documented at the central precinct (Andrews and Fash 2005), energetic data are limited for some of those structures, including those associated with the first two rulers (Carrelli 2004) and some temple and palatial structures built during the eighth century CE (Abrams 1987, 1994; Webster and Kirker 1995). Abrams (1994) estimated labor costs for sub-royal and intermediate elite and non-elite residences outside the Main Group. All these published measures are used in this study. For per capita labor costs I use population estimates by Webster et al. (1992), which range from 3,000 people in 400 CE to 5,500 people in 600 CE to c. 10,000 people in 650 CE and to c. 28,000 people in 750 CE (which include the rural areas).

Integration of samples from a broad range of excavated architectural complexes, including the central precinct and non-elite residences, allows a comparison of a fuller spectrum of socioeconomic statuses and contributes significantly to an understanding of the range of power differentials at Teotihuacan and Copan.

Multiscalar comparisons between Teotihuacan and Copan

The extent and degree of state power

As is clear from the significant difference in scale, the total labor costs for the precinct area during the Miccaotli to Early Xolalpan phases are

considerably greater at Teotihuacan (9,000,000 to 12,000,000 person-days) than at Copan (175,000 to < 1,240,000 person-days). This indicates a significant difference in the scale of state power and reflects the population size. However, the difference in per capita labor costs, a measure for the degree of state power, was likely less significant.

At Teotihuacan, per capita labor costs are more or less constant throughout time (350–400 days per person; see Figure 12.3; see Murakami 2015) with the exception of the final phase. Although data on the diachronic changes in the volume of buildings are largely unavailable at Copan at this time, Carrelli's (2004) labor estimate for structures commissioned by the first and second rulers and a rough estimate for the largest temple at Copan (Webster and Kirker 1995) can be used to compare the variability in the degree of state power. Carrelli (2004) estimated the total labor costs for royal construction at 175,000 person-days in the reign of the first ruler (Level 1) and 190,000 person-days (Level 2) and 271,000 person-days (Level 3) in the reign of the second ruler (a total of 461,000 person-days for the second ruler) both in the early half of the fifth century CE (see Table 12.1). Using a

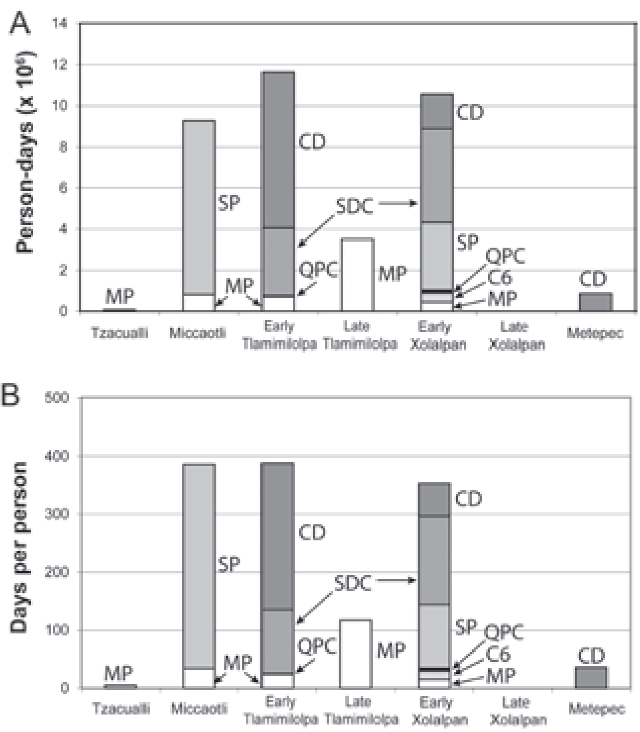

Figure 12.3 Diachronic changes in total (A) and per capita (B) labor costs for the central precinct at Teotihuacan (CD = Ciudadela; SDC = Street of the Dead Complex; SP = Sun Pyramid; QPC = Quetzalpapalotl Palace Complex; C6 = Complex 6: N5W1; MP = Moon Pyramid)

Table 12.1 Labor costs for state buildings at Teotihuacan and Copan (based on Murakami 2015, Carrelli 2004, Abrams 1994, and Webster and Kirker 1995)

*Structure**	*Phase assignment*	*Total labor cost (person-days)*	*Per capita labor cost (days)*
Teotihuacan			
MP Building 1	Tzacualli	28,970	1.81
MP Building 2	Miccaotli	29,460	1.84
MP Building 3	Miccaotli	16,790	1.05
MP Building 4	Miccaotli	826,160	34.42
MP Building 5	Early Tlamimilolpa	719,710	23.99
MP Building 6	Late Tlamimilolpa	3,509,380	116.98
MP Building 7	Early Xolalpan	458,900	15.3
Complex 6:N5W1	Early Xolalpan	440,130	14.67
QPC (1)	Early Tlamimilolpa	39,220	1.31
QPC (2)	Early Xolalpan	139,520	4.65
Sun Pyramid (1)	Miccaotli	8,431,900	351.33
Sun Pyramid (2)	Early Xolalpan	3,287,600	109.59
SDC (1)	Early Tlamimilolpa	3,305,490	110.18
SDC (2)	Early Xolalpan	4,557,010	151.9
Ciudadela (1)	Early Tlamimilolpa	7,572,770	252.43
Ciudadela (2)	Early Xolalpan	1,693,160	56.44
Ciudadela (3)	Metepec	865,760	36.07
Copan			
Central Precinct Level 1	425–435 CE	175,425	250
Central Precinct Level 2	435–440 CE	189,892	270
Central Precinct Level 3	440–450 CE	271,128	387
Structure 10L-22	715 CE	24,700	4.4
Structure 10L-26	750 CE	124,000	22

* MP: Moon Pyramid; QPC: Quetzalpapalotl Palace Complex; SDC: Street of the Dead Complex. The number in parenthesis indicates different building/rebuilding episodes.

population figure of 3,500 (700 laborers) in 450 CE (Webster and Kirker 1995, Table 6), analysis yields figures of c. 250 days per person and 660 days per person for the first and second rulers, respectively. These figures are about 60–70% to 165–190% of the per capita labor costs for the central precinct at Teotihuacan during the Miccaotli through Early Xolalpan phase. This indicates that the degree of state power was much greater at Copan during the reign of the second ruler than at Teotihuacan. The scale of royal construction increased subsequently at Copan (e.g. Andrews and Fash 2005; Fash 2001; Sharer, Miller, and Traxler 1992; Sharer et al. 2005), and it is likely that per capita labor costs increased accordingly since the total population did not change significantly until 650 CE. Therefore, we can reasonably infer that Copan surpassed Teotihuacan in the degree of state power.

Around 600 to 750 CE, the height of the Copan Acropolis reached its final version (Sharer, Miller, and Traxler 1992) and it is likely that a considerable

amount of labor was expended. However, the total population in the Copan Valley doubled in this period (Webster and Kirker 1995, Table 6). It is possible that the growth of construction activities just paralleled the population increase and per capita labor costs did not increase in a significant way. Webster and Kirker (1995) provide a rough estimate of labor costs for Temple 26 (Structure 10L-26), one of the largest single structures at Copan, which was built around 750 CE (124,000 person-days, not considering its earlier substructures). Using the population figure of 28,000 people (5,600 laborers), analysis yields per capita labor costs of 22 days per person. As a single structure, the costs approximate Building 5 of the Moon Pyramid (24 days per person) at Teotihuacan although they are far less than the Sun Pyramid (351 days per person) and Building 6 of the Moon Pyramid (117 days per person) and slightly less than the Feathered Serpent Pyramid (35 days per person) (see Table 12.1; see also Murakami 2015, Table 3). There is no base to estimate labor costs for the whole precinct area at Copan, but even if we assume that ten such temples were built at one time at Copan (which clearly exceeds the total amount of construction), per capita labor costs (c. 220 days per person) remain even less than those during the reign of the first and second rulers. Along with the rebuilding of the Acropolis, the rebuilding of the Main Plaza was exacerbated raising the floor level around 700–750 CE (Cheek 1986), which would also correspond to the population increase. Thus, it seems reasonable to infer that there was no significant increase in per capita labor costs at Copan and the degree of power of the Copan state remained more or less constant, probably with some fluctuations and not vastly different from that of Teotihuacan throughout its history.

Relations among state elites/institutions

My analysis (Murakami 2010, 2016a) suggests decentralizing processes through time as we see a transition from an early focus on ceremonial structures (major pyramids) to a later focus on administrative/residential structures (see Figure 12.3). During Teotihuacan's Miccaotli phase (150–250 CE) labor expenditure was highly concentrated in a single architectural complex (the Sun Pyramid), which suggests that governmental institutions were centrally organized, most likely under strong rulership. Place making is an actual process of building political authority (Smith 2003), and the construction of the central pyramids can be interpreted as the material manifestation of centralized governmental institutions and the identity of a political community (Murakami 2014). In subsequent phases, labor was allocated more proportionately to multiple complexes (see Figure 12.3). This implies that power became more widely shared by multiple institutions in the Early Tlamimilolpa and Early Xolalpan phases. Moreover, labor investment in administrative and residential structures increased through time (Murakami 2016a, Figure 6.4): about 24% of the total labor costs were invested for administrative/residential structures in the Early Tlamimilolpa phase,

whereas the proportion increased to 51% in the Early Xolalpan phase. This emphasis on administrative/residential structures in the Early Xolalpan phase probably speaks to the increased power of the inhabitants of those structures and/or their activities.

At Copan during the Late Classic, state institutions were not as much internally differentiated as at Teotihuacan, at least judging from architectural organization. Labor costs for Structure 10L-22, a palatial structure, are estimated at c. 24,700 person-days (Abrams 1994), whereas labor costs for Structure 10L-26, a pyramid of a public nature, are estimated at 124,000 person-days (Webster and Kirker 1995). Although the estimate for Structure 10L-26 did not consider the presence of substructure and thus the actual labor costs should be much less than estimated, even a half of the estimated labor costs are still twice the costs for Structure 10L-22. Moreover, as mentioned above, the Main Plaza was raised during 700–750 CE (Cheek 1986). Therefore, labor costs for palatial structures (and structures for other state officials) as a whole probably did not surpass those of public structures, a contrasting pattern with Teotihuacan. It is likely that relations among ruling elites did not change substantially at Copan, whereas relations among state elites and institutions became increasingly diversified and decentralized through time at Teotihuacan.

Relations among subjects

The results for a sample of six compounds (see Table 12.2) show that there is little variation in total labor costs among different compounds (see Figure 12.4A). The total labor costs for all the compounds fall between 130,000 and 165,000 person-days. Surprisingly, the compound of the lowest status in my sample (La Ventilla III) was ranked in the middle. This is attributable to a higher proportion of roofed area at La Ventilla III (labor costs for roofing appear to be very expensive). La Ventilla I has the largest central courtyard along with numerous temple structures, but it turned out that the total labor costs were the lowest among my samples, probably due to a higher proportion of open spaces. The same applies to Zacuala Palace and Yayahuala, both of which contained a large central courtyard.

Table 12.2 Labor costs for apartment compounds at Teotihuacan

	Total area (m^2)	*Main courtyard (m^2)*	*Number of units*	*Total labor cost (p-d)*	*Per unit labor cost (p-d)*
La Ventilla I	4,514	450	4	131,594.7	32,898.7
La Ventilla II	4,160	114	9	158,873.4	17,652.6
La Ventilla III	4,875	35	28	157,660.4	5,630.7
Tetitla	4,096	120	8	163,918.8	20,489.9
Yayahuala	3,600	181	7	136,242.2	19,463.2
Zacuala Palace	4,259.5	268	6	145,618.7	24,269.8

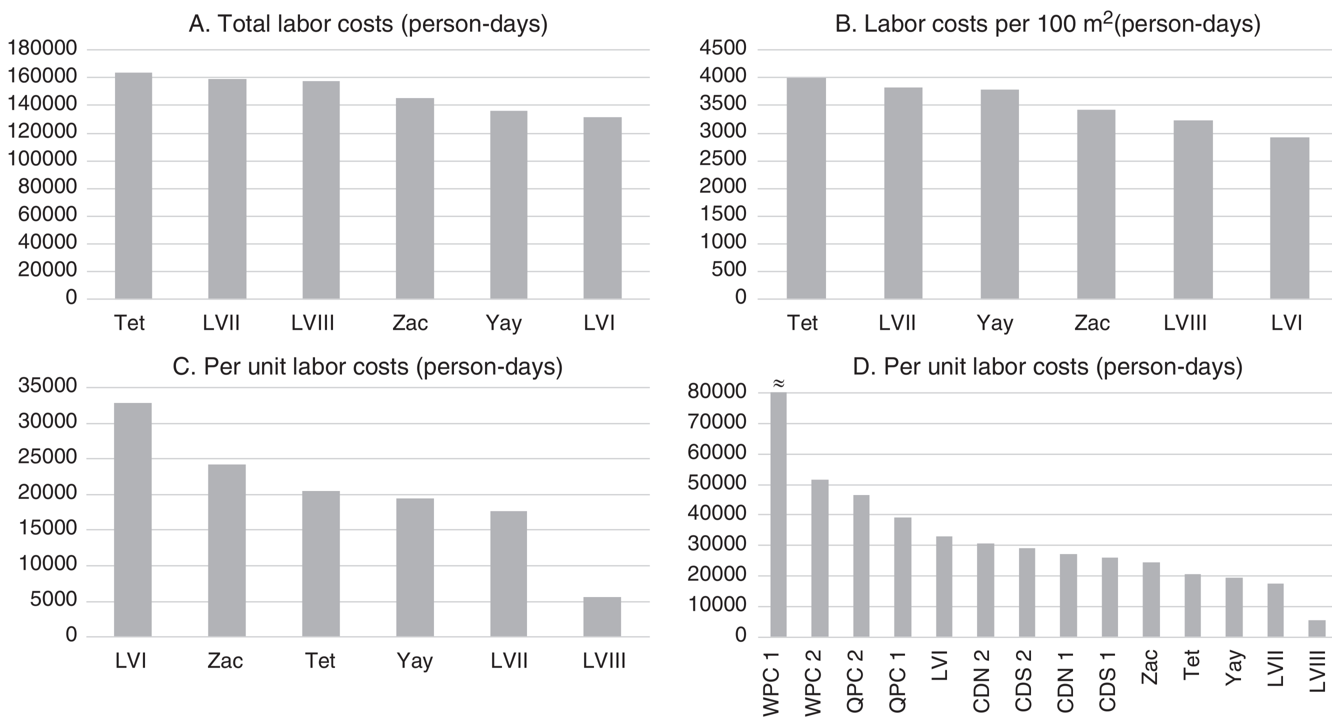

Figure 12.4 Comparison of labor costs among apartment compounds (A-C; LVI = La Ventilla I; LVII = La Ventilla II; LVIII = La Ventilla III; Tet = Tetitla; Zac = Zacuala Palace; Yay = Yayahuala) and between apartment compounds and some residential/administrative complexes within the central precinct (WPC = West Plaza Complex; QPC = Quetzalpapalotl Palace Complex; CDN = North Palace at the Ciudadela; CDS = South Palace at the Ciudadela; 1 = the Early Tlamimilolpa phase; 2 = the Early Xolalpan phase). * Labor costs for WPC1 are c. 330,000 person-days (not shown in the figure)

Since the total area of the compounds varies from 3,600 m^2 at Tetitla to c. 4,900 m^2 at La Ventilla III, I calculated labor costs per 100 m^2 for each compound to see the effects of difference in the total area to total labor costs. The results (see Figure 12.4B) show that, as with the total labor costs, those compounds with a larger roofed area (Tetitla and La Ventilla II) are ranked high, but La Ventilla III is now ranked lower. This reflects low quality of construction materials: it is estimated that about 40% of its walls were made of adobe bricks instead of masonry.

Overall, the proportion of roofed area, the size of the compound, and the quality of construction materials account for the variations in total labor costs for apartment compounds. Thus, there is no apparent correlation between total labor costs and socioeconomic status of the compound. It should be noted, however, that the labor costs for mural paintings are not included in the analysis, which would increase to some extent the total labor costs for intermediate elite compounds.

Each apartment compound consists of multiple apartments or residential units (courtyard units), each of which presumably housed a group of people related to each other through kinship, occupation, and/or institutional (e.g. religious) affiliations. The number of residential units varies among different compounds and so does the number of residents. To examine the variations in labor investment per resident, I standardized the total labor costs by the number of residential units for each apartment compound, assuming that each unit was continuously occupied by the same number of residents on average (probably around five).

The results (see Figure 12.4C) show that per unit labor investments vary greatly from c. 5,000 person-days to more than 30,000 person-days. La Ventilla I stands as the most powerful compound, followed by Zacuala Palace. These two compounds have a large central courtyard and have been interpreted as barrio centers or barrio temples (Cabrera C. and Gómez Chávez 2008; Gómez Chávez 2000; Manzanilla 2009, 2006). The per resident labor investment for Tetitla, Yayahuala, and La Ventilla II appears to be less than possible barrio centers, and these compounds may be characterized as having a more or less comparable degree of power. However, it is likely that these three compounds are functionally different: Tetitla seems to be a typical residential compound, an aggregate of more or less independent apartments like La Ventilla III. Yayahuala looks more like a barrio center: it has a main entrance leading to the central courtyard, and different courtyard units are spatially more integrated (see Millon 1976). But Yayahuala contains a larger residential area than possible barrio centers (Manzanilla 2009). La Ventilla II may be characterized as in between Tetitla and Yayahuala. Further research is necessary to identify possible functional differences among these compounds, but my analysis suggests that these compounds housed intermediate elites whose socioeconomic status is lower than those who lived in possible barrio centers.

There is a gap between La Ventilla III and the rest of the apartment compounds in my sample, which implies that the degree of power of the residents at La Ventilla III was substantially lower. Although it is not clear to what extent per unit labor investment for La Ventilla III is different from that for other middle to lower status apartment compounds, I suspect that La Ventilla III represents the average of those middle to lower status compounds based on the quality of construction materials. At Oztoyahualco 15B lime plaster was more abundantly used than at La Ventilla III (see Manzanilla 1993) and thus per unit labor investment was probably higher. At Tlajinga 33, the use of lime plaster and clay amalgam seems more restricted (at least during the Early Tlamimilolpa to Early Xolalpan phases; Widmer 1987), and per unit labor investment was likely much lower than at La Ventilla III. Based on these observations, I suggest that there was a gap in the degree of power between intermediate elites and middle to lower status people.

Based on available data, it is possible to discern some chronological trends in the construction of apartment compounds (Murakami 2010, 239–243). All the compounds in my sample were rebuilt subsequently in the Xolalpan and Metepec phases. It is likely that rebuilding of structures was intensified from the Late Xolalpan (c. 450–550 CE) to Metepec phases (c. 550–650 CE) (see Murakami 2010, Table 4.2). Available data show that the extent of rebuilding varies among different compounds as well as among different residential units within a single compound. The variations in the extent of rebuilding episodes would reflect differences in labor investment and thus differences in the extent and degree of power. Although the quantification of labor for rebuilding episodes is not possible at this point, I have an impression that apartment compounds (and residential units within single compounds) of higher status were rebuilt more extensively. This implies an increasing gap in power through time among apartment compounds as well as among residential units of differing socioeconomic status. This last point is still preliminary and needs to be tested through further research.

At Copan during the Late Classic, Abrams' (1994) analysis clearly demonstrates hierarchical relations among subjects. Residences are grouped into courtyard units equivalent to Teotihuacan's apartment compounds, and there are variations between courtyard units as well as within them. For both total labor costs and per residence labor costs (both in person-days), Group 9N-8A stands out as the most powerful courtyard unit (see Table 12.3; Figure 12.5). This group contains the House of the Bacabs (Structure 9N-82), whose lineage or house head was a courtier and was closely related to the sixteenth ruler (Webster 1989). After Group 9N-8A, there is an intermediate level of labor expenditure (9N-8B, C, E, and F and 9M-22A and B) and then the vast majority of non-elite population (see Figure 12.5). If courtyard units formed some corporate entities, then there were probably three major, and pronounced, levels of social statuses under the royal elites (sub-royal elites, intermediate elites, and non-elite population; cf. Abrams 1994). This contrasts with more continuous power differentials among subjects at

Table 12.3 Total and per residence labor costs for courtyard units at Copan (based on Abrams 1994)

Courtyard unit	*Total labor costs (p-d)*	*Number of residences*	*Per residence labor costs (p-d)*
9N-8A	33,054	6	5,509.0
9N-8B	17,080	7	2,440.0
9M-22A	14,275	8	1,784.4
9N-8C	7,744	3	2,581.3
9N-8E	4,216	2	2,108.0
9M-22B	2,395	5	479.0
9N-8F	1,665	1	1,665.0
9M-24	223	3	74.3
Site 11D-11-2	140	3	46.7
Site 30-7	136	3	45.3
Site 7D-6-2	124	2	62.0
Site 7D-3-1	60	2	30.0

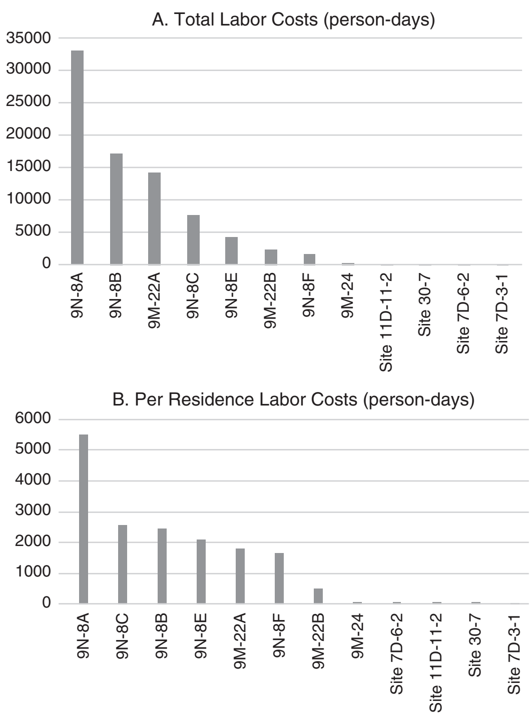

Figure 12.5 Comparison of total (A) and per residence (B) labor costs among courtyard units outside the Main Group (calculated based on the data from Abrams 1994)

Teotihuacan. It should be noted that, as detailed in Abrams (1994), sub-royal and intermediate elite compounds at Copan contain lower-status residences, probably retainers and servants for those elites.

There are no sufficient data to reconstruct chronological trends in the construction of courtyard units, but stratigraphic excavations at Group 9M-8A revealed a smaller courtyard and much less embellished structures around it during the Middle Classic (Fash 2001, Figure 43). This suggests increasing power differentials among the residents through time, a similar pattern to Teotihuacan.

State-subject relationship

In this final section I examine the differential distribution of power, which is expressed as the degree to which the consumption of labor is concentrated in the central precinct. For Teotihuacan, I focus on the Tlamimilolpa/Early Xolalpan phases because the quantification of labor for the rebuilding of apartment compounds in subsequent phases is not possible at this point.

I estimate the total labor costs for all the apartment compounds (c. 2,000) based on labor costs generated for a sample of compounds (see above). Since the size of apartment compounds varies widely while the total labor costs do not, I use the average labor costs per 100 m^2 or 3,528.9 person-days as a baseline. Estimating the average size of apartment compounds is a difficult task. It is often stated that a square compound with 60 m on a side (3,600 m^2) is a typical apartment compound, but most of my samples are larger, while there are others much smaller than this (e.g. Tlajinga 33). Cowgill (2008, 91) mentions that the median size of apartment compounds is about 1,830 m^2 (43 × 43 m). For this study I use 1,830 m^2 and 3,600 m^2 as the possible range of the average size. Thus, the range of the average total labor costs for one typical apartment compound will be about 64,599 to 127,080 person-days. Multiplying this figure by 2,000, the total labor costs for all the apartment compounds will be between 129 million and 254 million person-days.

Most apartment compounds were founded probably during the Late Tlamimilolpa phase and some others were built during the Early Tlamimilolpa and Early Xolalpan phases (Millon 1981, 206). Assuming that the construction of all the apartment compounds was completed by the end of the Early Xolalpan phase, I compare the total labor costs for all the apartment compounds with cumulative total labor costs from the Early Tlamimilolpa to Early Xolalpan phases for the central precinct. The result clearly shows that much more labor was invested in the construction of apartment compounds than in the central precinct. The total labor costs for the central precinct during the Tlamimilolpa/Xolalpan phases are about 26 million person-days, a bit more than one- or two-tenths of the costs for the apartment compounds. In terms of the degree to which labor investment was concentrated in the central precinct, only about 9% to 17% of the total

labor used for urban construction during the Tlamimilolpa/Xolalpan phases were invested in the central precinct.

For Copan, it is possible to calculate the total labor costs expended in houses outside the Main Group based on Abrams' (1994) labor estimates for residences to illustrate the state-subject relationship. The mean of total labor costs for sub-royal elite (5% of all residences), intermediate elite (10%), and non-elite residences (85%) are estimated at 6,777.5 person-days (average of Clusters 2 and 3 in Abrams 1994, Figure 15), 1,878 person-days (Cluster 4), and 47 person-days (Cluster 6), respectively. Based on a set of assumptions (e.g. Clusters 2–4 residences are only within the urban core; labor costs for residences did not change significantly through time), the total labor costs for 750 CE may be estimated at c. 602,600 person-days (3,360 residences). Considering the population for 400 CE (3,000) is about 11% of the population for 750 CE (28,000), the total labor costs for all the residences in 400 CE would be c. 64,566 person-days, which is significantly below the total labor costs for royal buildings (around 15–35% of the costs for royal buildings). There is no firm base to infer the total labor costs for royal buildings in 750 CE, but the value for all the residences is more or less equivalent to the costs for five of Temple 26. I assume that this value would approximate the total labor costs for the Main Group (or at least greater than 35%). Therefore, it is possible that the consumption of labor was concentrated to a greater degree in the central precinct early on and became more proportionately distributed among different social segments during the later phases. This possible change seems to reflect population growth and probably decentralization associated with the increasing power of intermediate elites, as seen at Group 9N-8A (see above).

In order to further examine the state-subject relationship, I compare labor costs for residential/administrative compounds within the central precinct with those for residential compounds outside it. At Teotihuacan, I include the West Plaza Compound (a sub-complex of the Street of the Dead Complex), the Quetzalpapalotl Palace Complex, and the North and South Palaces at the Ciudadela (all for two phases; 1 for early and 2 for late). The results (see Figure 12.4D) show a continuous distribution of per unit labor costs except for the West Plaza Compound during the first phase. Interestingly, labor costs for La Ventilla I are greater than both the North and South Palaces at the Ciudadela. In contrast, at Copan there seems to be a great gap in labor costs between Structure 10L-22 and Group 9N-8A, the most powerful courtyard unit outside the Main Group. If we include all the buildings at the East Court (part of which is Structure 10L-22), this gap would be even greater.

Summary

Multiscalar comparisons between Teotihuacan and Copan have revealed some similarities as well as differences in power relations embodied in

architecture. While the extent of state power, as reflected in total labor costs for state buildings (and the population size), is vastly different between the two cities, the relative degree of state power turned out to be not as different; Copan during the reign of the second ruler could have been more centralized than Teotihuacan. This seems surprising in view of the significant difference in the scale of state power, but it accords well with an observation that "It is easier for a small than a very large state to centralize" (Southall 1988, 81). Thus, the grandeur of monumental structures at Teotihuacan was not necessarily the result of a greater degree of centralization but can be attributable to the state's organizational skills to extract labor from a larger populace and to specific historical contexts in which these monuments were constructed. Although the scale of state buildings increased through time at Copan, it is likely that it paralleled population increase and not necessarily the increase in the degree of state power.

The centralized state government at the two cities underwent divergent trajectories after the initial place making. At Copan, both the scale and diversity of architectural complexes increased, but both ceremonial structures and palatial compounds were basically replicated through time. In contrast, labor expenditure for major pyramids decreased through time at Teotihuacan while that for administrative/residential structures increased especially during the Early Xolalpan phase, indicative of a state decentralization process. I have argued elsewhere (Murakami 2010, 2016a) that the change in the labor allocation within the central precinct suggests increasing power of bureaucrats or state officials.

While power relations among subjects can be characterized as hierarchical at both cities, there is a broader spectrum of labor costs between residential compounds within the central precinct, intermediate elite compounds, and other apartment compounds at Teotihuacan. Moreover, there are variations (though not quantified) within single apartment compounds (e.g. Tetitla and La Ventilla III), crosscutting differences between various compounds. These variabilities also are reflected in the distribution of wealth/prestige items (Manzanilla 2001). All this suggests fluid social mobility. I have argued that bureaucrats (at least in the lower echelons) were widely recruited from intermediate elites and possible middle to lower status people (Murakami 2010, 2016a). In contrast, there is a huge gap in labor investment between sub-royal elites, intermediate elites, and the general populace at Copan. This may suggest more restricted social mobility than at Teotihuacan.

The contrast in the relations among subjects between the two cities reflects differing state-subject relationships. Power relations between state elites and subject population at Copan can be characterized as centralized and contrast significantly with power relations at Teotihuacan during the Late Tlamimilolpa/Early Xolalpan phases, where the total labor costs for all the apartment compounds are considerably higher than those for the central precinct. This is attributable to the difference in construction materials, labor organization, and the varying exercise of state power. At Copan, most

non-elite houses were built with wattle and daub (Abrams 1994, 22–23), which contrast with solid masonry (or adobe) buildings at Teotihuacan. Abrams (1994) suggests that various reciprocal and redistributive labor systems were employed for the construction of non-elite residences at Copan, whereas it is likely that the state subsidized labor and materials for the construction of apartment compounds at Teotihuacan (Murakami 2010, 2016a, 2016b, n.d.). These different practices in residential construction were clearly related to the contrasting nature of state power and state-subject relationships. While the Teotihuacan state exercised a strong infrastructural power during the Late Tlamimilolpa/Early Xolalpan phases, the exercise of infrastructural power was highly restricted at Copan throughout its history (at least for construction activities). These differences are also reflected in the urban form (nucleated versus dispersed residences).

Despite all these differences, power relations during the final phases show some similarities. Several scholars (e.g. Webster 2002; Fash 2001; Freter and Abrams 2016) suggest that internal conflict between ruling elites and sub-royal and intermediate elites was one of the factors that led to the dissolution of the Copan kingdom. My study also suggested that such conflict or competition between ruling and intermediate elites contributed to the eventual collapse of the Teotihuacan state (Murakami 2010, 2016b; see also Manzanilla 2006, 2009). Whether or not such conflict was one of the causes of state collapse, the rise of intermediate elites is a common feature at both sites and characterizes power relations in their final phases.

Discussion: political dimensions of urban construction

The results of multiscalar comparisons imply that differences in the relations among state elites, state-subject relationships, and the relations among subjects are associated with one another and, together, suggest divergent trajectories of changing power relations at Teotihuacan and Copan. Early Teotihuacan (before the urban renewal) and Copan (most parts of its history) demonstrate somewhat similar patterns (in their centralized government and centralized state-subject relationships). During the Late Tlamimilolpa/Early Xolalpan phases Teotihuacan's government became decentralized along with the decentralization of the state-subject relationship and possibly the increased infrastructural power of the state. Since there were no drastic changes in population size or in the extent of state power in this transition, the overall decentralization process likely resulted from the negotiation among social groups (Murakami 2016a) in specific historic and cultural contexts.

Previous studies (e.g. Blanton and Fargher 2011, 2012; Fletcher 1995; Feinman and Nicholas 2012) demonstrate that polities with pronounced infrastructural power tend to exhibit dense and compact urban settlements with well-organized neighborhoods because such urban elements facilitate intra-urban communication and allow ruling elites to deeply penetrate

resident communities. In contrast, polities with strong despotic power and polities that are weak in both despotic and infrastructural power tend to exhibit dispersed urban settlements or near-absence of cities (e.g. Blanton and Fargher 2011). Such associations are, however, general tendencies and by no means automatic. Moreover, the causal relationship among these variables is not clear due to the synchronic nature of comparative studies. This study suggests that dense (nucleated) population and possibly relatively well-organized neighborhoods (Robertson 2001) provided a generative mechanism for the development of infrastructural power at Teotihuacan (see Bettencourt 2013; Ortman et al. 2015; Latham 2009). In other words, dense urban settlement with diverse social groups provided an arena for heightened social negotiation, which resulted in a polity with greater infrastructural power at Teotihuacan. Besides population density and neighborhood organization, the degree of planning and the presence of a consistent type of civic building or complex for administrative districts are also important indicators of the nature of social integration (e.g. Cowgill 2004; Freidel 1981; Smith 2010, 151). The grid-like urban planning, the presence of talud-tablero style temples at multiple apartment compounds, and the construction of apartment compounds itself, all indicate a more integrated nature of social relations and a shared urban identity (Murakami 2014).

The contrast in terms of low-density and high-density urbanism may be attributed to environmental differences (that is, highlands versus tropical; see Fletcher 1995). However, urban form is by no means uniform in the Maya lowlands (Chase and Chase 2016) and environment alone does not explain specific urban form (see Isendahl and Smith 2013). Therefore, social factors along with historically contingent process should be brought to the foreground to explain the resultant low-density urban form at Copan. Judging from the results of this study, I emphasize that limited social mobility as seen in relations among subjects and between ruling elites, other elites, and the non-elite population may have played a role in restricting the arena for social negotiation. Moreover, the materiality of residences in the Copan Valley might not have required cooperation beyond kin and relatives (Abrams 1994), different from Teotihuacan's apartment compounds where cooperation among more people was necessary (Murakami 2010). This further restricted social interaction at multiple scales at Copan, which may have resulted in a weaker social integration.

It is likely that Copan during its final years underwent a similar process of decentralization as at Teotihuacan. Population size and density doubled twice at around 650 CE and 750 CE (Webster, Sanders, and Rossum 1992), and accordingly the state-subject relationship became decentralized along with increasing power of sub-royal and intermediate elites who shared similar types of architecture and glyphic inscriptions with royal elites in the Main Group. This may reflect the effect of the increasing scale of the city. Studies of urban scaling suggest a close relationship between the scale

and population density, on the one hand, and the nature and frequency of social interaction, on the other (see Bettencourt 2013). It is possible that the ruling elites and the subjects were better integrated with increasing infrastructural power of the state. A wide distribution of polychrome vessels (Copador and Ulua) in all socioeconomic strata might attest to this process (see Fash 2001). Such social integration would provide a source of shared urban identity but also opportunities for various social segments to share state symbols and thus a source of social power and to challenge the central authority. Factional competition is predicated on the integration of various social groups, and both later Copan and Teotihuacan were sufficiently integrated to provide social, economic, and ideological contexts for competition among elite groups, which would have contributed to the eventual dissolution of state systems.

Conclusion

The multiscalar comparison between Teotihuacan and Copan, though preliminary in nature, demonstrates that detailed analyses of architecture from varying social segments provide useful tools to better understand sociopolitical dynamics and the variability among different polities. Political strategies and the differential development of despotic and infrastructural power are not the results only of the decisions and actions of ruling elites but are predicated on the entanglement of multiple individuals and social groups with varying interests and capacities (Murakami 2016a). Architectural settings along with construction activities provide an important arena for social negotiation among these individuals and groups, which, in turn, reproduces and transforms the preexisting urban landscape. Hence, the different urban forms and organization would represent both the media and consequences of negotiation at multiple scales of social interaction and the divergent processes of social transformation.

Unfortunately, there are few sites in Mesoamerica, and beyond, which can be compared in a similar way as Teotihuacan and Copan, and much more research is needed along this line. Studies of the sociopolitical dimensions of architecture have tended to focus on monumental structures (or buildings commissioned by ruling elites) with little attention to buildings of other social segments such as intermediate elites and the non-elite population (e.g. Trigger 1990). While these studies were successful in demonstrating that many ancient complex societies experienced a rapid increase in the size and grandeur of monuments in their formative periods (e.g. Adams 1966; Kolb 1994; Trigger 1990), a strong central authority embodied in monumental structures does not necessarily imply weak and passive subjects. Conversely, a reduction in the scale of monumental structures does not always imply reduction in the power of ruling elites (such as at Teotihuacan during the Early Xolalpan phase). We need to pay more attention to how the actions and decisions of dominant elites were articulated with those of the rest of

the populace to better understand changing power relations and to integrate traditionally dichotomous top-down and bottom-up approaches. Furthermore, a recent focus on the development of the public realm (e.g. Inomata, MacLellan, and Burham 2015) has advanced our understanding of the initial stage of early complex societies, and architectural energetics will certainly contribute to elucidating social process associated with the creation of monumental landscape (see McCurdy, Chapter 10).

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13 The future of architectural energetics in 2D and 3D

Leah McCurdy and Elliot M. Abrams

This volume celebrates and expands upon the 25 years of architectural energetics application in archaeology since Abrams' (1994) synthesis in *How the Maya Built Their World*. This collaboration offers new analytical expansions and global explorations. To conclude the volume in this chapter, we set the stage for more expansion with recommendations for continuing the scholarship encompassed in this volume and the corpus of architectural energetic studies.

Firstly, one major contribution of this volume is the scope of our geographic applications. Kim and Heo (Chapter 2) present comparative cases from northern and southeast Asia. Drennan and Kolb (Chapter 3) focus on ancient pharaonic Egypt. Remise (Chapter 4), Lancaster (Chapter 5), and Kolb, Kirk, and Balco (Chapter 6) provide regionally and chronologically distinct cases from Europe and the Mediterranean. Moving to the Americas, Davis, Burks, and Abrams (Chapter 7) along with Lacquement (Chapter 8) focus on indigenous cultures of North America. DeLuca (Chapter 9) and McCurdy (Chapter 10) offer applications to Mesoamerican contexts while Smailes (Chapter 11) presents a study from the South American Andean region. To conclude and bookend the case studies, Murakami (Chapter 12) presents a comparative view between Mesoamerican contemporaries.

This range of studies focused on architectural energetics presented together is unprecedented. It demonstrates the value and potential of the approach across a broad spectrum of histories and contexts. Further, it enables collaboration of scholars investigating architecture, construction, labor, and power as social intersections with great import for our understanding of the past and present (see also Brysbaert et al., in press). The complex variety of relations of social and political power that are evident in the modern world emerged in the archaeological past. These sociopolitical dynamics are reflected most directly and conspicuously in the architectural projects accomplished by past societies. Quantifying those projects in terms of comparative time-labor estimates is the basis for architectural energetics and considering what labor investment can help us learn about powerful people and laborers.

In our view, the major goals for architectural energetic studies moving forward include expanding geographic and chronological applications and

considering the comparative value of such studies for addressing "big" questions of the shared human experience. These new applications should be conducted as contextually and effectively as possible. Thus, we suggest a number of ways to proceed in continuing and enhancing this approach.

Recommendations

Our recommendations derive from our combined experience with architectural energetics, the collaboration evident in this volume, and our vision of the potential of this approach. At the most fundamental level and as mentioned above, we recommend applying architectural energetics to as many contexts as possible. Further, in that process of geographic and chronological expansion, we strongly recommend documentation of and investment in developing work rates that are as contextual and accurate as possible, with the caveat that they will almost always be reconstructive (without documentary records, for example). Third, we emphasize the value of digital, virtual, and 3D technologies to enhance the efficiency and effectiveness of energetic analyses. Next, we suggest the interpretive and/or comparative theme of non-state explorations to expand the ways in which archaeology understands complexity, beyond traditional limits of linear social evolution schemes. Lastly, we ask a new question: how can we build bridges to contemporary life and future challenges through energetic studies of the past?

Expand across the globe

Our major recommendation and hope for energetics studies moving forward is simple: more and in new places and times. Some of the newest contexts to which architectural energetics has been applied recently are in Asia. Kim and Heo's study (Chapter 2) represents one of the few considerations of Asian contexts. Other notable contributions include that from Liye Xie and colleagues (2015) focused on Neolithic Chinese earthen wall construction.

The more analyses we have within the corpus of energetics studies, the more we are able to refine estimates and develop comparative understandings of construction, power, and/or labor across related contexts. As evidenced in this volume, comparative studies between neighboring contexts (Kim and Heo, Chapter 2) and associated social systems (Murakami, Chapter 12) offer new layers of evidence and insight to external relationships, sociopolitical ties, and the nature of power across societies. As Murakami (Chapter 12) emphasizes to conclude his chapter, the comparative approach requires more studies from which to develop relevant and appropriate comparisons. A forthcoming volume edited by Ann Brysbaert and colleagues, entitled *Constructing Monuments: Perceiving Monumentality and the Economics of Building*, promises to be an excellent resource of case studies relevant to interests in global comparative views of monumentality and construction.

Other avenues of comparative inquiry could stem, for example, from relatively new considerations of the parallels of low density agrarian cities (Isendhal and Smith 2013) of Mesoamerica and Southeast Asia (the topic of a symposium entitled "Comparative Approaches to Complexity in the Tropics" at the 2016 Annual Meeting of the Society for American Archaeology chaired by Scott Macrae). Further, Arco and Abrams (2006) have demonstrated the effectiveness of energetics as applied to agricultural infrastructure construction. Comparative energetic studies of features such as Aztec *chinampas*, Olmec *islotes*, and Balinese water temple networks could open a broader, quantified view of subsistence-based collective effort, cooperation, and/or labor control. Studies regarding the relationship of subsistence and monumental construction labor in a variety of contexts could follow.

Contextual and accurate work rates

Another fundamental recommendation for architectural energetics is to continue to add to the range and accuracy of work rates available (see Table 1.1). Many contributors to this volume discuss their measured selection of work rates, carefully considering environmental context, contextual resource availability, and accuracy of technological availability. These site-specific considerations are paramount for the development of contextual and accurate energetic estimates. Further, contextualized considerations of workday length should account for differing conditions in temperate, tropical, arid, and other environments.

In addition, Remise (Chapter 4) thoroughly considers the applicability of generalized work rates, such as those for transport costs. It is obvious that we need more work rates. Thus, experimental studies designed to produce historically accurate task costs in particular landscapes are crucial to the continued development of energetics studies. Further, it is critical that variables such as soil density, stone type, material usage, and technique are thoroughly reported for such experimental studies to inform future researchers as much as possible about the contextual value of work rates developed through specific experimental conditions.

Consider 3D

Some of the exciting innovations focused upon in this volume involve digital, virtual, and 3D technologies as they can apply to architectural energetics. There are many opportunities and options for incorporating digital and/or virtual technologies into the architectural energetics approach. As Drennan and Kolb (Chapter 3) demonstrate, there are existing resources such as the UCLA Digital Karnak project with potential for collaboration and/or open access. Other potential collaborators with already-developed 3D virtual resources include CyArk and Learning Sites, Inc, for example.

Davis and colleagues (Chapter 7) describe their methodology to use photogrammetric data capture and modeling to derive a fully accurate 3D model of the famous Serpent Mound. First considering less nuanced alternatives, they indicate that a simplified model of the main body of the serpent effigy returns a volumetric total of 830 m^3. Using the photogrammetric model, and thus a more complex understanding of the main body's contour and mass, their digitally derived volumetric estimate is 747.5 m^3. This comparison amounts to a 10% difference in the estimate. Thus, labor projections derived from the simplified calculation would reflect 10% more effort than is actually evidenced in the mound. The order of magnitude of either overestimation or underestimation significantly increases if manual geometric calculations are employed to develop volumetric estimates. Lancaster (personal communication 2018) plans to explore how the difference of manual and digital volumetrics affects his analysis of Archaic Sicilian building events (see Chapter 5) in an upcoming project. We look forward to his results as an explicit test of the improvements 3D and digital methods can make to architectural energetics.

McCurdy's (Chapter 10) study and use of virtual architectural reconstruction demonstrates the fundamental documentary value of virtual resources. McCurdy's models derive from a multilayered database of archaeological data, literature references, reconstruction hypotheses, and transparency paradata about those reconstructive decisions. As such, these models serve as cross-referenced data storage with a visual and geometrically quantifiable output. As McCurdy discusses, this output serves to increase the accuracy and speed of volumetric analyses. Thus, 3D virtual techniques enhance the efficiency and effectiveness of energetics in a similar way to Davis and colleagues' (Chapter 7) use of photogrammetric modeling with the additional layer of reconstruction of partially surviving remains.

Digital and virtual methodologies have great potential for recording and visualizing buildings or features under investigation, expediting energetic analyses, and providing venues for complex data storage. As technologies develop, experimentation with their potential for architectural energetics will be important. We strongly encourage the adoption of new techniques to make the energetics process faster and more efficient. This will increase the likelihood of a broad range of scholars applying this approach to their sites and contexts; and thus, building the set of case studies available for consultation and comparison.

Consider non-state contexts

As Davis and colleagues (Chapter 7) emphasize, the potential of architectural energetics has principally been applied to the remains of state-level societies. These traditional studies are important, as they provide quantified and direct means to understand power relations and the material ways in which leaders invested their power in subordinate communities. The study of Salemi Castle by Kolb and colleagues (Chapter 6) is an excellent example

of the value of this perspective. It is also important to explore non-traditional avenues of application and consider the other side of the power coin.

Davis and colleagues' (Chapter 7) consideration of Serpent Mound in connection with Lacquement's (Chapter 8) study of the later site of Moundville represent an informative spectrum of labor investment that would not be available if early, non-state contexts were not investigated. DeLuca's (Chapter 9) study of ritual architecture within the Late Formative corporate society of Teuchitlán offers a perspective on the energetics of a distinct political system, as compared to neighboring and later state societies of Mesoamerica (see McCurdy, Chapter 10; Murakami, Chapter 12).

As Murakami (Chapter 12) notes, elite-associated features and the elite perspective in construction have also been disproportionately analyzed. Importantly, Abrams' (1994) application of energetics to Classic period Copán involved not only the highest elite residence of the site, but a wide spectrum of residential units representing the range of socioeconomic status within Maya society at that time. With respect to elite labor control, Smailes' (Chapter 11) analysis of Chimu construction labor at Chan Chan correlates with the lower-than-expected labor estimates of Abrams' (1994) early studies. Such results suggest that "massive assumptions" (Abrams and McCurdy, Chapter 1) of elite labor control arguments are often inflated and not accurate reflections of labor dynamics in many ancient contexts. In fact, one of the consistent empirical results throughout this volume is that labor input, when quantified and annualized, was generally never as demanding as one might imagine. Lacquement's (Chapter 8) focus on kin-based labor relationships within Mississippian moundbuilding and Lancaster's (Chapter 5) considerations of small colonist populations of Archaic Sicily are additional innovative ways to broaden the range of contexts to which energetics can be applied. Further, McCurdy's (Chapter 10) "peopled" approach to labor among the Classic period Maya and Murakami's (Chapter 12) comparative Mesoamerican view explore the limits of simplified elite labor control arguments, in either non-state or state contexts.

In all, we suggest that broadening the horizons of architectural energetics beyond state societies and monumental architecture will enhance its analytical potential. Further, we suspect that additional investigations of non-state collective effort, be that through architectural construction, agricultural investment, or some other form of material investment, will reveal our underestimation of what smaller-scale societies could achieve. There is great potential for new insights into the value and "power" of cooperative social and political strategies that have been and continue to be understudied in archaeology.

What is the value today?

We still build. We still labor. We still invest effort in collective projects. We still attempt to manifest power in monuments. As architectural energetics

moves forward within the discipline of archaeology, we encourage considerations of how newfound understandings of past collective achievement, labor dynamics, sociopolitical power, and construction can impact and/or enhance life today. Such considerations may best be spawned from investigations that embrace anthropological approaches and/or incorporate ethnographic endeavors as well.

What can insights regarding the value of collective labor and cooperative investment in the past yield in light of growing competitive tensions and sociopolitical distrust? As archaeology continues to mature, it becomes increasingly important for the discipline to provide a historically informed voice to contemporary debates and issues. The implications of power and labor studies derived through architectural energetics can form an important piece in the puzzle of archaeology's modern social relevance.

As a final note, we are reminded that the most important audience of archaeological insights about past architectural projects is the public at large but also those most directly connected to the past builders. This audience wants to know how these past architectural works were built and what scale of labor organization was required for the successful completion of these projects since these works are a sincere source of pride for many people today. It is incumbent upon archaeologists to strive to provide the most accurate answers to this audience and hopefully this volume has moved the methodology necessary to offer those answers forward.

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